# A multi-agent framework for container booking and slot allocation in maritime shipping

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Digitalization is constantly altering company paradigms and expanding cross-border supply chain prospects. Maritime transportation plays an increasingly essential part in the global supply network. Since maritime shipping services need to exchange a huge number of papers and paperwork across numerous companies, the usage of a unified platform for inter-organizational communication and information sharing is required. To develop an integrative, adaptive and intelligent container booking system, a multi-agent architecture is designed in this article. The proposed architecture will aid the maritime industry in establishing real-time information interchange between autonomous agents, shippers, freight forwarders, and shipping lines. The process outlined in this paper reveals how the agents communicate with one another to resolve underlying inconsistencies. With the multi-agent framework, the article also presents a container slot optimization problem considering market segmentation, different booking periods, heterogeneous containers and port congestion scenarios. Using this model the managers can find the booking limit for each type of containers and accordingly they can accept or reject the incoming booking requests. Furthermore, a simulated case study is also provided to validate the model.

Keywords: multi-agent architecture; maritime shipping; container booking; slot allocation.

## 1. Introduction

Maritime shipping is the backbone of global trade, with 80 percent of all products transported by waterways. The worldwide maritime containerized trade is predicted to be responsible for roughly 60% of overall maritime market in terms of value, which valued at around $14 trillion in 2019 (Statista 2021). Containerized trade is responsible for 24% of overall dry freight shipments in 2018 (UNCTAD 2019). Container transportation is expanding rapidly due to its security, economies of scale, and convenience reliability as the global economy continues to develop. Several industries like maritime transportation, have had their business and partnership models altered by digitalization, which has enhanced information efficiency, visibility, and performance. The marine sector is evolving from a traditional logistics network to a digital freight logistics network (Orji et al. 2020). Shippers, shipping companies, consignees, government agencies, forwarders, and similar businesses can all benefit from digitalization since it makes them more efficient (Yang 2019).

On the other hand, the marine supply chain still lies in the beginning phases of digitalization. The maritime shipping industry is different from other sectors, like retail. It contains a number of parties, such as, the buyer (or consignee), the supplier (or shipper), logistics service supplier (e.g., second-tier forwarder, first-tier forwarder, shipping line, and truck service supplier), along with international and national authorities and organisations as the International Maritime Organization (Zeng et al. 2021; Zeng et al. 2020). As a result, operational actions between firms in the maritime shipping are constrained to a greater extent than in other industries. Furthermore, this marine business is an oligopoly, with only a few companies dominating the majority of the market. The five major shipping lines account for roughly 53% of the overall market, whereas the ten major account for about 82 percent (Alphaliner 2021). Given the industry's particular qualities, it's important to consider this scenario while looking into digitalization in the maritime shipping. The booking process of shipping containers is one of the most important operations in the marine shipping chain, and engages the supply chain's main players. So it will be beneficial to develop a multi-agent architecture for container booking to increase the revenue and efficiency.

In liner shipping, shipping companies manage incoming requests in liner shipping, and in most situations, they must evaluate whether a booking should be approved or cancelled right away. They usually have a lot of experience in this field, but they hardly employ decision support tools. As a result, they usually depend on a First Come First Serve (FCFS) policy to achieve optimal ship utilisation. Moreover, particularly when ship capacity is limited, the shipping company should strive to accept the most profitable bookings considering present capacity. Therefore, selection of these booking is extremely important. Shipping services provided by a shipping company follow fixed schedules and itineraries. Although these services help the shipping industry by allowing it to canvass cargo shipment demand, the dependence on a predetermined ship schedule implies that ships may not be completely filled up while leaving a port. As a result, shipping companies require an efficient container slot allocating method to allocate limited capacity. The method necessitates meeting shippers' shipping demands while simultaneously increasing cargo shipping profit. Using the revenue management and slot allocating models, the shipping manager can find the booking limits and choose whether to accept or reject a certain booking request.

This study contributes to the literature of maritime shipping by proposing a multi-agent architecture for the container booking system and a decision support model to reject or accept a booking request. This architecture can improve the chain relationships by integrating and aligning external and internal processes, sharing real-time data, and coordinating the flow of information to optimize the supply chain. A multi-agent system connecting all the players of container booking system on a single platform is the first contribution of the paper. The second contribution of the paper lies in the container slot allocation model which can be used by the booking agent to decide whether to reject or accept the request. The main aim of this optimization model is to maximize the overall revenue of the shipping company by allocating the slots depending on the remaining capacity.

The remaining paper is organized as follows. A brief survey of the associated literature is presented in Section 2. Section 3 presents a multi-agent framework for shipping container booking. Section 4 proposes and formulates the container slot allocating problem in the form of a mixed-integer non-linear programming problem. Section 5 contains a simulated case study of the container booking process. Section 6 highlights the managerial insights of the proposed work. Finally, concluding remarks and future scope of the work are discussed in Section 7.

## 2. Literature review

### *2.1. Container booking in maritime shipping*

The maritime sector may now attain higher efficiency and performance due to advances in technology. However, in the logistics sector, digitalization looks to be lagging behind different industries like media and retail (Sanchez-Gonzalez et al. 2019; WTO 2019). Maritime transport includes a high number of complex players and necessitates the exchange of several documents, which might impede efficiency. While shipping a container, nearly 40 different entities may be engaged and several documents are to be exchanged between them. This study follows the definition of container booking system proposed by Zeng et al. (2020); where they stated that the process "involves a series of activities from the initial request of booking a container, the release of container from shipping line and the loading of the container, to the arrival of the container in the port, and its release by the customs offices". The major entities involved in the chain (i.e., second-tier forwarder, first-tier forwarder, shipping line, manufacturer, and trading firm) still communicate through conventional tools like telephone, e-mails, and instant messengers. These current operations necessitate an automated system capable of bringing all maritime shipping stakeholders onto a single platform with minimal human intervention. Taking this into account, this article proposes an automated technique that would put numerous shipping company stakeholders onto the same platform and be capable of efficiently addressing internal as well as external disturbances in container booking system processes. Therefore, the implementation of such multi-agent framework will aid in the development of a more digitalized maritime supply chain.

Due to large number of stakeholders involved in the maritime shipping industry compared to other industries, implementation of container e-booking systems is complicated and have received less academic attention. Zeng et al. (2020) are one of the first researchers to investigate the adoption of inter-organizational information systems in the context of maritime shipping and analyse at a chain level using the Technology-Organization-Environment Framework (TOE). Further, the same authors have discussed the container booking process and looked into the inter-organizational and intra-organizational elements that influence the adoption of e-booking in the maritime industry (Zeng et al. 2021). They studied the gap between general understanding of information system adoption and the use of e-booking systems in the maritime supply chain. They carried out an exploratory multi-case study involving eight companies from various tiers of the maritime supply chain. They have realized the need of e-booking system. Based on their results, we have proposed a multi-agent framework that leads to a container e-booking system. Also, the multi-agent architecture proposed in the maritime supply chain context is automated and self-adaptive in nature due to its ability to multi-tasking of all agents. The agents collaborate in a single society to solve a common problem by combining their resources and knowledge. The proposed framework will help to take a suitable measure to mitigate the supply chain uncertainty. It will also aid in real-time data monitoring i.e., tracking the locations of the containerized cargo. Although these two above-mentioned papers have investigated the process and need of e-booking systems, they have not considered the decision-making reflecting when the company should accept or reject an incoming booking request in the system.

### *2.2. Multi-agent system (MAS)*

The application of a multi-agent system promotes effective communication in the process of container booking. Distributed and Artificial Intelligence are the foundations of the notion of MAS. Agents collaborate to develop accurate solutions to complex issues and problems with minimal human involvement. This idea has been used by several scholars to solve problems in scheduling, design, and planning (Li et al. 2010). A multi-agent model for load demand management of a shipboard power system is developed by Du et al. (2019). Furthermore, a multi-agent system approach has been developed to efficiently convey information and to address the Master Bay Plan Problem (MBPP) in maritime logistics (Parthibaraj et al. 2017). Also, an information exchange system (IES) is built in the intended MAS approach for the stowage planners. MAS has features such as social interaction, dynamic, self-adaptive, and autonomy (Moyaux et al. 2006). Chao and Sun (2013) redesigned and combined the multi-sites and multi-roles of an IT office-aid asset distribution chain into an empirically effective multi-agent based cooperative cloud service. This resulted in minimizing labour costs, boosting system performance, and alleviating operational concerns in the supply chain. Moreover, Yu et al. (2017) suggested a multi-agent negotiation mechanism to address the supplier selection problem. Coria et al. (2014) suggested a tool based on multi-agent systems for flexible and autonomous compilation of business processes.

Mishra et al. (2012) suggested a multi-agent architecture to address recyclable materials and reverse logistics concerns, while considering waste classification. Also there are several applications of MAS in the manufacturing industry, such as, Mishra et al. (2016) proposed a self-adaptive multi agent framework to develop real time data exchange among suppliers, clients, agents, and production units. Similarly, a self-reactive automated multi-agent system is designed in Kumari et al. (2015) to assist SMEs to reduce supply chain unpredictability, to complete manufacturing process more quickly and reduce machine spare time with minimal human interference. Cost savings, availability and processing of real-time data, quicker deployment, increased agility, adaptability, and decreased IT technical assistance staff are just a few of the primary benefits of cloud computing based multi-agent systems (Guo et al. 2014; Oliveira and Handfield 2019; Liu et al. 2019; Ali et al. 2021; Yu et al. 2017; Maqueira et al. 2019). This system offers a wide range of applications in the automotive industry, finance, medicine, education, and logistics.

### *2.3. Container slot allocation and Revenue Management*

The problem of container slot allocation has been investigated by several researchers. Maragos (1994) was the first to look into the issue of slot allocation and pricing. But this study did not explore empty container repositioning. Using segmentation, revenue management approaches such as bid-price (BP) strategy, booking limits, and nested booking limits can be utilized to determine if a specific booking request has to be approved or rejected. In this context, Zurheide and Fischer (2015) compared and contrasted various booking acceptance techniques, and evaluated their applicability in liner shipping as well as their profitability and capacity utilization, using a slot allocation model for container bookings. Wang et al. (2019) addressed a container slot allocation model and provided overbooking and delivery-postponed approaches to maximize profitability. A container management problem is presented by Chang et al. (2014) for optimally allocating loaded container slots and empty container repositioning in liner service. Recently, Wang et al. (2020) proposed a container slot allocating problem for time sensitive freight under demand uncertainty, taking into account dynamic pricing. But they have not taken into account the heterogeneous nature of the laden as well as empty containers. Later, the same authors solved the container slot allocation problem as a two-stage stochastic non-linear MIP model using the sample average approximation integrated with dual decomposition and Lagrangian relaxation techniques (Wang et al. 2021). In addition to this paper, we have also considered different scenarios for port congestion. Hence, we have proposed a unified system of a multi-agent architecture to handle all the operations of container booking process efficiently and a decision support model to decide acceptance or rejection of an incoming booking request.

This study develops a self-adaptive multi-agent system to facilitate the efficient integration and communication between multiple tiers involved in container booking in maritime supply chain. The strength of this automated system is its agents' ability to multitask precisely. In container shipping, carriers monitor incoming bookings, and they have to decide whether to confirm or cancel a booking immediately. Furthermore, when ship capacity is restricted, the company must accept the most profitable bookings for the existing capacity. Hence, in liner shipping, slot allocation, or allocating available space to incoming booking requests, is a key issue. Since the First Come First Serve (FCFS) strategy is not always profitable, it may be more lucrative to reject a booking and wait for an even more profitable future booking if capacity is restricted. In this study, along with the multi-agent system we have presented a container slot optimization model that will help to choose if a booking request has to be approved or rejected based upon the slot allocation.

## 3. Multi-agent Framework

The proposed multi-agent architecture for liner shipping container booking is presented in fig 1. It involves supplier selection agent, order collection agent, shipping agent, second-tier forwarding agent, first-tier forwarding agent, knowledge base agent, shipping line agent, customs agent and administrative agent. All of these agents collaborate with one another. All the informations are stored in the knowledge base agent through which the agents can access any information related to other agents. These agents communicate with one another utilizing the Multi-agent logic language for encoding Teamwork (MALLET), which is an agent communication language. The following are the attributes of each agent:

< Insert figure 1 here >

Figure 1. Multi-agent architecture.

Figure 1 Alt text. The figure depicts the multi-agent architecture for liner shipping container booking involving supplier selection agent, order collection agent, shipping agent, second-tier forwarding agent, first-tier forwarding agent, knowledge base agent, shipping line agent, customs agent and administrative agent. All of these agents collaborate with one another.

### *3.1. Order collection agent*

This agent will receive the order from the buyer. The buyer will ask for a quote from the agent when looking for purchasing goods. The quote comes with or in as a proforma invoice. This invoice is merely an estimate and it can be changed later. A commercial invoice, on the other hand, is the final and formal invoice that is utilized for customs declarations. The order collection agent will interact with the supplier selection agent and provide him the information regarding the quotation. If the selected supplier approves the quote, the agent will create a purchase order on behalf of the buyer. A purchase order is a contract that outlines the order's contents as well as the price of the products. A detailed purchase order may additionally include origin and destination addresses, an estimated shipping date, and freight measurements, depending on the business. While issuing a purchase order, the agent will make sure that one of the several incoterms should control the contract. When it comes to shipping, Incoterms are essentially the agreements that define the costs and risks between the buyer and the supplier. Throughout its activities, the order collection agent constantly updates the knowledge base agent. It is also capable of updating itself both online and offline.

### *3.2. Supplier selection agent*

As early as the order collection agent provides information about the quotations to the supplier selection agent, they begin looking for a suitable supplier. Alternatively, this agent can use professional relationships and networking to locate suitable suppliers over the Internet. They can also ask business acquaintances and friends for recommendations. While identifying the potential supplier, they look for reliability, consistent quality, good service, financial stability and price, keep a balance between these criteria. After shortlisting, they contact potential suppliers and make a Request For Quote (RFQ) or Request For Proposal (RFP), as well as a product sample if necessary. When they receive quotations from all promising suppliers, the suitable supplier is selected by comparing the quotations.

### *3.3. Shipping agent*

The responsibility of a shipping agent is to find a shipper who will export the goods on behalf of the supplier. A shipper is a person or a company responsible for transportation, packaging and tagging of the goods and cargo appropriately whilst the goods are moving from origin to destination. The responsibility of transporting products and commodities is delegated to the shipper. In some cases, the supplier can be itself the shipper. However, to find the suitable shipper, the agent looks for the best shipping rate, reviews the features and services of shippers with proper licences and certifications such as, expected speed of delivery and also checks the shipper provides insurance or not. The shipping agent runs a background check on the shippers considered to ensure they have a good track record. The shipper also handles all documentation required to complete the transportation operation, ensuring that there are no disruptions in the cargo delivery process. The bill of lading is an example of the required documentation. The shipping agent interacts with the buyer and shipper, and collects all the information about the necessary documentation. At the same time, it keeps the knowledge base agent updated.

### *3.4. Second-tier forwarding agent*

This agent assembles all the information from the shipper about the cargo shipment needed to be exported. These information include the type of cargo (general cargo, dangerous goods cargo or refrigerated cargo), loading port, destination port, cargo volume, cargo weight, container type (20’ dry, 40’ dry or 40’ high cube), number of containers, desired schedule, and other special requests if any. Then the second-tier forwarding agent starts searching for the best matching second-tier freight forwarding service according to the shipper’s needs. They assess the customer service quality and also check if the freight forwarder is well-connected with other forwarders and transportation companies. After selecting a potential second-tier freight forwarder, the agent sends a booking request to the forwarder according to the requirements of the shipper. If the booking request is approved, the agent passes the information from the second-tier freight forwarder to the shipper and then the forwarder picks up the goods from the suppliers' warehouse and transports them to a designated warehouse, sometimes owned or leased by the freight forwarding firm. This process is known as Export Haulage. All the details about the container booking and transportation of goods between shipper and second-tier forwarder are stored by this agent so that the shipments can be tracked and the knowledge base agent is updated.

### *3.5. First-tier forwarding agent*

The first-tier forwarding agent collects all the information from the second-tier freight forwarder regarding the shipments and selects a first-tier freight forwarder who oversees the transportation of the cargo from the second-tier forwarder's warehouse and its packaging and loading into the carrier. The agent notifies the first-tier forwarder about the booking information. If the booking request is approved, the agent passes the information from the first-tier freight forwarder to the second-tier freight forwarder and then the first-tier forwarder picks up the goods from the second-tier forwarder's warehouse, transports and loads into the containers hired from the shipping company. The first-tier freight forwarder also produces documentation to customs, who must approve the items' departure from the nation of origin. This agent can communicate with customs agents in other countries to confirm that the products and paperwork comply with local requirements.

### *3.6. Shipping line agent*

The shipping line agent sends the booking request from the first-tier freight forwarder to the shipping line or company which is also selected by the agent. A shipping line is a company that owns or leases the ships that transport the containers and freight from the loading port to the discharge port. The container booking information such as the type of cargo, loading port, destination port, cargo volume, cargo weight, container type, number of containers is received by the shipping line through the agent. The booking is processed by the shipping line, and the booking information is exchanged amongst all of the organizations. The booking confirmation contains shipper name, consignee name, vessel name, container size and quantity, expected time of departure or expected time of arrival, port of loading/port of discharge, CY(Container Yard) Date, CY cut-off date (the date by which a container must be checked-in at the container yard before its scheduled sailing), shipping line name. The agent will help to make decisions concerning the acceptance/rejection of booking requests using a decision support system to maximize the possible revenue for the shipping line. When a booking request comes, the shipping line agent can find the remaining space for the concerned booking type and approve the request if there is space. Otherwise, the request has to be refused in order to maximize the company's revenue.

### *3.7. Customs agent*

It is necessary to complete export custom clearance when shipping cargo by sea. All enterprises that export goods from the country must clear various customs restrictions that the government has set up. A standard part of the customs clearance procedure is preparing documents to be submitted online or offline with the consignment. This makes it easier for the authorities to calculate the cargo's duties and charges. The official documents of export permission from the government are required depending on the cargo. The documents like customs packing list, proforma invoice, country of origin (or COO) certificate, shipping bill, commercial invoice, airway bill or bill of lading, bill of sight, bill of exchange, warehouse receipt, letter of credit export license, and health certificates are required for exports customs clearance. In this connection, customs agent extracts all the information about the cargo shipment and helps the shipper to prepare and submit the customs clearance documents in advance. If the shipper fails to arrange the proper documentation, the cargo will not be exported or will fail to pass through customs clearance at the destination.

### *3.8. Knowledge base agent*

It collaborates with other agents such as the supplier selection agent, order collection agent, shipping agent, second-tier forwarding agent, first-tier forwarding agent, shipping line agent, customs agent, and administrative agent, among others. The knowledge base agent stores all of the information about the whole booking process and cargo movement. The role of the agent is to gather all the data from the agents and monitor how they fulfil their responsibilities. This agent is aware of the present status of operations in progress for container booking. The knowledge base agent also keeps track of the moving shipments throughout the booking and transport activities. It also takes account of all of the agents' successful and unsuccessful decisions. It aids in preventing similar errors from occurring in the future.

### *3.9. Administrative agent*

It takes care of all other agents' activities and makes sure they are legitimate. This agent is in charge of guarantees, warranties, agreements, health and safety precautions, and transportation security, among other things. In addition, the administrative agent oversees all financial accounts, including payments to suppliers, staff salaries, consumer payments, and other activities.

### *3.10. Communication ontology*

Only those agents who fall inside an agent's perceptory region can communicate with it. Agent collaboration and knowledge dispersion are ensured with such a communication channel. It defines a communication language and standardises the interaction between computational beings. The most common application of communication ontology is during the approach to a cooperative task, in which an agent opens a communication channel with another agent in its perceptual range by sending a 'help' signal. One agent works with other agents in this multi-agent system by providing 'help' signals. Agents inside the sender's perceptor range can only respond to this signal. The $m^{\text{th}}$ agent sends a 'help' signal $S_m^w$ requesting cooperative assistance in task $w$, which may be described mathematically as:

$$S_m^w = (a_m, w_m) \quad \forall A^{PR_m} \tag{1}$$

Where $A^{PR_m}$ represents the collection of agents inside agent $m$'s perceptory range (PR) and can be expressed as:

$$A^{PR_m} = \left\{ a_n^{PR_m} \mid a_n \in a \right\} \; and \; a_m \notin A^{PR_m} \tag{2}$$

where, $a_n^{PR_m}$ denotes the $n^{\text{th}}$ agent that resides in the $m^{\text{th}}$ agent's perceptory range. Eq. (2) represents the collection of agents inside agent m's perceptory range (PR) and it says that $a_m$ should not be in the set $A^{PR_m}$.

$$|d_{mn}| < PR_m \tag{3}$$

$|d_{mn}|$ presents the distance between the $m^{\text{th}}$ and $n^{\text{th}}$ agent and by eq. (3) it should be less than the perceptory range of agent $m$. Manhattan distance has been used in this multi-agent framework because it is more effective than Euclidean distance in a parallel computing scenario (Kumar and Mishra 2011). Agent *n* sends a ‘reply’ signal $r_{mn}$, after receipt of a ‘help’ signal from agent $m$; $r_{mn}$ is defined as:

$$r_{mn} = (a_n, a_m, S_m^w) \quad (4)$$

Figure 2 shows the communication between all agents involved in the container booking process and how they are connected with each other.

< Insert figure 2 here >

Figure 2. Container booking scenario and interaction between agents.

Figure 2 Alt text. The figure shows the container booking process and how the agents interact with each other.

### *3.11. Communication channel*

The effectiveness of a multi agent architecture is governed by the agents' ability to communicate properly. The agents use signals to communicate with one another. Agents take necessary measures as soon as they get signals. A variety of communication channels, such as Knowledge Query Manipulation Language (KQML), Agent Communication Language, and others have been proposed before for effective conversation amid agents. Multi-Agent Logic Language for Encoding Teamwork (MALLET) is among the most developed and extensively used languages. For communication, MALLET adopts team-centered programming. MALLET facilitates good transition of information in the system as well as precise encoding of data by employing sequential and iterative methods. This iterative procedures can be declarative or procedural in nature. MALLET will be used by the agents in the system to promote effective and exact communication among them and it is interpreted by Collaborative Agents for Simulating Teamwork (CAST). Figure 3 represents the CAST architecture for the proposed multi-agent system.

< Insert figure 3 here >

Figure 3. CAST architecture for multi-agent system

Figure 3 Alt text. The figure represents the CAST architecture for the proposed multi-agent system. The agents communicate with one another utilizing the Multi-agent logic language for encoding Teamwork (MALLET), which is an agent communication language**.** MALLET will be used by the agents in the system to promote effective and exact communication among them and it is interpreted by Collaborative Agents for Simulating Teamwork (CAST).

Prior to starting communication, agents describe their duties, skills, and work plans. Then, depending on their condition, they combine their tasks with those of other agents. The next agent then conveys the previous agent its prerequisites, such as necessary information and knowledge. The interaction between the agents may be Iterative (WHILE, FOR), Sequential (SEQ), Parallel (PAR), Conditional (IF) or Choice specific (CHOICE). Only when all the pre-requisites are met, the agents begin executing their duty. If a single agent fails to meet the pre-requisites in some way, other agents assist it.

## 4. Container slot allocation model

In this section, the container slot allocation model needed to approve or reject the incoming booking requests by the shipping line agent is presented and formulated mathematically with the aim of maximizing overall revenue for the shipping company. In liner shipping industry, the company can segment shippers into two types: spot shippers and contract shippers (D. Liu and Yang 2015). To draw attention of the contract shippers and ensure a stable profit, the liner company offers preferential charges for freight to the contract shippers and provides a contract dictating that a set of containers will be delivered over a specified time, referred to as "contract containers". On other hand, a spot customer is charged with high freight rate for remaining slots on the ship. Hence, the shipping line agent can approve bookings depending on available slots for containers and these are known as "ad hoc containers". Approving all requests from the contract shippers is certainly not the optimal option for the company, as keeping booking open for ad hoc shippers can generate higher profit. As a result, the preferred option for the organization is to sign a bond stating a predetermined least amount will be reserved for contract shippers. Hence, the shipping company keeps specific slots for the contract customers.

Although the booking of ad hoc containers is quite uncertain, but it definitely generates more revenue. It can be noted that freight rate for contract containers is determined as per the shipping company and contract shippers. On the other hand, the freight rate for ad-hoc containers depends upon the company only and can also vary. Spot shippers can hire slots about a specific time until the ship leaves at each port. Let $T$ denote the booking period horizon, and $\tau = \{1,2,..t,..T\}$ denote the set of booking periods. Thus, spot shippers can reserve container slots at time $t$. The greater the value of $t$ as the booking time approaches the final booking deadline. Also, some ports require empty containers due to any disparity between ports. Hence, the shipping companies must retain some slots for empty container repositioning, which incurs additional costs. Considering these points, we have formulated the container slot allocation model as a mixed-integer non-linear programming problem (MINLP) and following are the notations for set, indices, parameters and decision variables:

### *4.1. Mathematical formulation*

*Set and Indices*

| | |
|---|---|
| $P$ | Set of ports, $p, q \in P$ |
| $M$ | Set of origin-destination pair, $M = \{(p,q) \mid p, q \in P\}$ |
| $I$ | Set of legs, $i \in I$ |

| | |
|---|---|
| $\tau$ | Set of periods *t* for booking of spot containers, $t \in \tau$ |
| $K$ | Set of types of containers, $k \in K$ |
| $R$ | Set of types of refrigerated or reefer containers, $k \in R$ |
| $S$ | Set of congestion scenarios, $s \in S$ |
| $P_k^{out}$ | Set of ports for outgoing empty containers of type *k* |
| $P_k^{in}$ | Set of ports for incoming empty containers of type *k* |

*Parameters*

| | |
|---|---|
| $Q_{0_k}^{(p,q)}$ | The basic freight rate of contract containers for origin-destination pair $(p, q)$ for container type *k* |
| $U^{(p,q)}$ | The delivery time negotiated for containers for origin-destination pair $(p, q)$ |
| $C_k^{(p,q)}$ | The transporting cost of an empty container of type *k* for origin-destination pair $(p, q)$ |
| $C_{kp}^L$ | The cost of leasing an empty container of type *k* for port *p* |
| $\delta^{(p,q)}$ | The estimated voyage time for origin-destination pair $(p, q)$ |
| CAP | Ship's slot capacity |
| $ED_{kq}$ | The demand at port *q* for empty containers of type *k* |
| $ES_{kp}$ | The available stock of empty containers of type $k$ at port *p* |
| $\bar{R}_{kt}^{(p,q)}$ | The maximum basic freight rate of the spot containers of type $k$ for origin-destination pair $(p, q)$ in booking period *t* |
| $\alpha_t^{(p,q)}, \beta_t^{(p,q)}$ | The coefficients in dynamic pricing function |
| $\theta_s$ | The probability of occurrence of port congestion scenario *s* |
| $\mu_i^{(p,q)}$ | Binary variable that equals 1 if the voyage for origin-destination pair $(p, q)$ includes leg *i* and 0 otherwise |
| $Q_{ks}^{(p,q)}$ | The actual freight rate of the contract containers type $k$ for origin-destination pair $(p, q)$ in scenario *s* |

| | |
|---|---|
| $\gamma_s^p$ | The waiting time at port $p$ in scenario $s$ |
| $d^{min}{}_k^{(p,q)}$ | The minimum demand for the contract containers of type $k$ for origin-destination pair $(p, q)$ |
| $\bar{d}_k^{(p,q)}$ | The maximum demand for the contract containers of type $k$ for origin-destination pair $(p, q)$ |
| $D_k$ | Dimension of container type $k$ |
| $m_k$ | Average weight of a type $k$ laden container (in tons) |
| $m_k^E$ | Weight of a type $k$ empty container (in tons) |
| $e$ | Penalty or incentive factor (USD per day per TEU). |

*Decision variables*

| | |
|---|---|
| $x_k^{(p,q)}$ | Number of slots allocated for $k$ type loaded containers for contract shippers for origin-destination pair $(p, q)$ |
| $y_{kt}^{(p,q)}$ | Number of slots allocated for $k$ type containers for spot shippers at booking time t for origin-destination pair $(p, q)$ |
| $z_k^{(p,q)}$ | Number of slots allocated for $k$ type empty containers for origin-destination pair $(p, q)$ |
| $x_{kp}^L$ | Number of $k$ type containers leased at port $p$ |
| $w_i^C$ | Number of allocated slots for contract containers on $i$th leg |
| $w_{it}^S$ | Number of allocated slots for spot containers on $i$th leg in booking period $t$. |
| $w_i^E$ | Number of allocated slots for empty containers on $i$th leg. |
| $R_0{}_{kt}^{(p,q)}$ | The basic freight rate of spot containers for origin-destination pair $(p, q)$ for container type $k$ in booking period $t$ |
| $R_{kts}^{(p,q)}$ | The actual freight rate for spot containers for origin-destination pair $(p, q)$ for container type $k$ in booking period $t$ in scenario $s$ |

*Objective*

The objective function (5) presents the overall revenue where the former portion is dedicated to contract market revenue and the next component is revenue from the spot market. The next two parts represent two costs: empty container repositioning cost and container leasing costs.

Maximize

$$\sum_{s\in S}\theta_s(\sum_{k\in K}\sum_{(p,q)\in M}Q_{ks}^{(p,q)}x_k^{(p,q)}+\sum_{k\in K}\sum_{t\in T}\sum_{(p,q)\in M}R_{kts}^{(p,q)}y_{kt}^{(p,q)}-\sum_{k\in K}\sum_{(p,q)\in M}C_k^{(p,q)}z_k^{(p,q)} -\sum_{k\in K}\sum_{p\in P}C_{kp}^{L}x_{kp}^{L}) \tag{5}$$

*Constraints*

$$Q_{0_k}^{(p,q)}\le R_{0_{kt}}^{(p,q)}\le \bar{R}_k^{(p,q)} \qquad \forall k\in K;\forall t\in T;\forall(p,q)\in M \tag{6}$$

$$y_{kt}^{(p,q)}=\alpha_t^{(p,q)}-\beta_t^{(p,q)}R_{0_{kt}}^{(p,q)} \qquad \forall k\in K;\forall t\in T;\forall(p,q)\in M \tag{7}$$

Constraints (6) define the span of basic freight rate and constraints (7) present a linear relation between the number of slots for spot shippers and freight rate. If the cargo is delivered late or ahead of schedule, the shipping companies should be charged or rewarded respectively. For late or early delivery, a penalty or an incentive can be considered. As a result, we can consider a new function for freight rate that takes shipping time into account (Wang and Li 2019). A basic freight cost can be taken when the container shipment is on schedule. The final freight rate will then be equal to the basic freight rate - (the penalty or incentive factor × the delivery time delay or advance). The delivery time comprises of voyage time and waiting time at port, including staying time while cargo loading or unloading service time and port congestion. In this study the staying time at any port is randomly generated following an independent exponential distribution (Tan et al. 2015)). Based on the assumptions, eq. (8) and eq. (9) respectively can represent the new functions for spot and contract container freight rates.

$$Q_{ks}^{(p,q)} = Q_{0_k}^{(p,q)} - e \times (\delta^{(p,q)} + \gamma_s^p - U^{(p,q)}) \qquad \forall (p,q) \in M; \forall k \in K; \forall s \in S \tag{8}$$

$$R_{kts}^{(p,q)} = R_{0_{kt}}^{(p,q)} - e \times (\delta^{(p,q)} + \gamma_s^p - U^{(p,q)}) \qquad \forall (p,q) \in M; \forall k \in K; \forall t \in T; \forall s \in S \tag{9}$$

$$w_i^C = \sum_{k \in K} D_k \sum_{(p,q) \in M} \mu_i^{(p,q)} x_k^{(p,q)} \qquad \forall i \in I \tag{10}$$

$$w_{it}^S = \sum_{k \in K} D_k \sum_{(p,q) \in M} \mu_i^{(p,q)} y_{kt}^{(p,q)} \qquad \forall i \in I; \forall t \in T \tag{11}$$

$$w_i^E = \sum_{k \in K} D_k \sum_{(p,q) \in M} \mu_i^{(p,q)} z_k^{(p,q)} \qquad \forall i \in I \tag{12}$$

$$w_i^C + \sum_{t \in T} w_{it}^S + w_i^E \le CAP \qquad \forall i \in I \tag{13}$$

$$\sum_{k \in K} m_k \sum_{(p,q) \in M} \mu_i^{(p,q)} (x_k^{(p,q)} + \sum_{t \in T} y_{kt}^{(p,q)}) + m_k^E \sum_{(p,q) \in M} \mu_i^{(p,q)} z_k^{(p,q)} \le DW \qquad \forall i \in I \tag{14}$$

$$\sum_{k \in R} D_k \sum_{(p,q) \in M} \sum_{i \in I} \mu_i^{(p,q)} \left( x_k^{(p,q)} + \sum_{t \in T} y_{kt}^{(p,q)} + z_k^{(p,q)} \right) \le RP \tag{15}$$

The numbers of allocated slots to contract containers, spot containers, and empty containers are represented by constraints (10)–(12) respectively. Constraints (13) enforce that the container number must not exceed total capacity of the leg. Constraints (14) ensure that the containers transported on each voyage leg must not exceed the deadweight restriction. Similarly, the number of available reefer plugs to be considered is represented by constraints (15).

$$\sum_{p \in P_k^{out}} z_k^{(p,q)} \geq ED_{kq} \qquad \forall q \in P_k^{in} \; \forall k \in K \tag{16}$$

$$z_k^{(p,q)} = 0, \text{ when } ED_{kp} > 0 \qquad \forall (p,q) \in M; \; \forall p \in P_k^{out}; \forall k \in K \tag{17}$$

$$\sum_{q \in P_k^{in}} z_k^{(p,q)} \leq ES_{kp} \;\; \forall p \in P_k^{out} \qquad \forall k \in K \tag{18}$$

$$x_k^{(p,q)} + \sum_{t \in T} y_{kt}^{(p,q)} + z_k^{(p,q)} = x_{kp}^{L} \qquad \forall (p,q) \in M \tag{19}$$

$$\overline{d}_k^{(p,q)} \geq x_k^{(p,q)} \geq d_k^{\min(p,q)} \qquad \forall (p,q) \in M; \; \forall k \in K \tag{20}$$

$$x_k^{(p,q)}, y_{kt}^{(p,q)}, z_k^{(p,q)}, x_{kp}^{L}, x_{kp}^{ST} \in \text{¢}^{+} \cup \{0\} \qquad \forall (p,q) \in M; \forall k \in K; \forall t \in T \tag{21}$$

Constraints (16) specify that the number of empty containers moved to port *q* must be greater than the demand of empty containers at port *q*. As indicated by constraints (17), no containers shall be sent out of port *q* if there exists a need for empty containers at that port. Constraints (18) indicate that the number of empty containers moved from port *p* to port *q* should not exceed the number of containers available at port *p*. Constraints (19) ensure that the total slots allocated is equal to the number of leased containers. The number of contract container slot allocation lies in the span provided in the constraints (20). Constraints (21) present that the number of allocated slots must be integers.

### *4.2. Linearization*

In the objective function (5), $\sum_{k \in K} \sum_{t \in T} \sum_{(p,q) \in M} R_{kts}^{(p,q)} y_{kt}^{(p,q)}$ is a non-linear expression. To linearize the objective, we have defined a new set, $F = \{1, 2, .. f, .. CAP\}$, which is the number of the slots allocated to spot shippers and two new variables, $\Lambda_{kf}^{(p,q)}$ and $\Delta_{ktsf}^{(p,q)}$. Some new constraints are added into the model in order to linearize it. The constraints are as follows:

$$\sum_{f\in F}\Lambda_{kf}^{(p,q)}=1 \qquad \forall(p,q)\in M;\ \forall k\in K \tag{22}$$

$$\sum_{f\in F}f\,\Lambda_{ktf}^{(p,q)}=y_{kt}^{(p,q)} \qquad \forall(p,q)\in M;\ \forall k\in K;\forall t\in T \tag{23}$$

$$\Delta_{ktsf}^{(p,q)}\le fR_{kts}^{(p,q)}+M\left(\Lambda_{ktf}^{(p,q)}-1\right) \qquad \forall(p,q)\in M;\ \forall k\in K;\ \forall t\in T;\forall s\in S \tag{24}$$

$\Lambda_{kf}^{(p,q)}$ is a binary variable such that $y_{kt}^{(p,q)}=f$ if $\Lambda_{kf}^{(p,q)}=1$. Constraints (22), (23), and (24) are the linearization constraints. Using these new constraints, the new linear objective function (25) will be:

$$\sum_{s\in S}\theta_s\Big(\sum_{k\in K}\sum_{(p,q)\in M}Q_{ks}^{(p,q)}x_k^{(p,q)}+\sum_{k\in K}\sum_{t\in T}\sum_{(p,q)\in M}\Delta_{kts}^{(p,q)}-\sum_{k\in K}\sum_{(p,q)\in M}C_k^{(p,q)}z_k^{(p,q)}-\sum_{k\in K}\sum_{p\in P}C_{kp}^{L}x_{kp}^{L}\Big) \tag{25}$$

## 5. Simulated case study

In this section, a simulated case study is presented to validate the proposed model. The container booking process is initiated with customer requests. In the multi-agent framework, the order collection agent, after receiving the order from customer or buyer (Company A), creates purchase order, interacts with the supplier selection agent and provides it the information regarding the quotation. The supplier selection agent finds a suitable manufacturing firm or supplier (Company B) and on behalf of the supplier, a shipper or a trading firm (Company C) exports the good. Let us consider three ports: Colombo, Singapore, and Xiamen. The sequence of port of call forming a route is as follows: Colombo → Singapore → Xiamen → Colombo. It is assumed that the customers need their purchased shipments to be transported considering the origin and destination pairs as (Colombo, Singapore), (Colombo, Xiamen), (Singapore, Colombo), (Singapore, Xiamen), (Xiamen, Colombo), and (Xiamen, Singapore). The shipping agent finds the suitable shipper (Company C) with the best shipping rate, services with proper license and certifications, best speed of delivery and other features.

The shipping agent interacts with the buyer and shipper, and collects all the information about the necessary documentation. Second-tier forwarder picks up the goods from the suppliers' warehouse and transports them to a designated warehouse, sometimes owned or leased by the freight forwarding firm. After selecting a potential second-tier freight forwarder (Company D) according to the shipper's needs, the second-tier forwarding agent sends a booking request to the forwarder according to the requirements of the shipper. The first-tier forwarding agent collects all the information from the second-tier freight forwarder regarding the shipments and selects a first-tier freight forwarder (Company E) who oversees the transportation of the cargo from the second-tier forwarder's warehouse and its packaging and loading into the carrier. Next, the shipping line agent sends the booking request from the first-tier freight forwarder to a shipping line (Company F) which is also selected by the agent.

Now, the shipping line agent will make decisions on behalf of the shipping Company F concerning the acceptance/rejection of booking requests using the decision support system provided here to maximize the possible revenue. When a booking request comes, the shipping line agent can find the remaining space for the concerned booking type and approve the request if there is space. Moreover, we have conducted a numerical experiment on how the shipping line agent allocates slots for different containers according to the shipment demand. The container ships have to satisfy the shipment demand of six origin-destination pairs. The capacity of the ship is 15000 TEUs. For spot shippers, the ordering period is divided into 6 days. (i.e. $T$ = 6). The route with weekly frequency deploys a fleet of two container ships, where each ship has a capacity of 15000 Twenty Equivalent Units (TEUs). The possible deadweight of the container ships is at most 1,65,500 tons. Let us assume that the ship has 1,500 reefer plugs. Six types of containers with varying weights and volumes are considered in our case study (provided in table 1) and the waiting time at the ports at different scenarios of port congestion are given in table 2.

< Insert Table 1 here >

Table 1. Volume and weight of different type of containers.

< Insert Table 2 here >

Table 2. Waiting time at the ports at different scenarios of port congestion.

Since freight rates and prices are classified data, they are difficult to access. Hence, these parameters are generated randomly in intervals using uniform distribution to depict the interrelationship among them. $\alpha_t^{(p,q)}$ is taken as ($\beta_t^{(p,q)}\times$ the basic freight rate for the spot market) plus a uniformly distributed random number, $U[1, 20]$. Next, $U^{(p,q)}$ is taken as $\delta^{(p,q)}$ plus a uniformly distributed random number, $U[1, 3]$. The penalty or incentive factor is taken as 100 USD/day/TEU. The freight rate of a 20' dry contract container is taken as the baseline for each port pair in this study. It is assumed that the demand for each origin-destination pair's contract market follows a normal distribution and the basic freight rate for the contract containers for each origin-destination pair is generated between [500, 1000]. The basic freight rates of 40' high cube and 40' dry contract containers are considered as 2 and 1.5 times higher than that of 20' dry containers for contract market. Since an empty container has no commission, insurance, or weighting costs, the empty container cost is considered as 50% of the cost of a contract container. In addition, due to temperature controlling facilities, the freight charge of a refrigerated container is 5% larger than the freight charge of a dry container. The upper limit for the freight rate for the spot shippers is assumed to be the basic freight rate for the contract market plus 2000. The empty container demand and stock at each port are uniformly distributed and randomly generated between [0, 500]. Based on these data, the linearized model is solved using CPLEX Studio IDE 20.1.0.

<Insert Figure 4 here>

Figure 4. Contract market revenue, empty container repositioning cost and container leasing cost for different booking periods.

Figure 4 Alt text. The figure shows the variations in the revenue for contract demand, empty container repositioning cost and container leasing cost while considering different booking periods of 2 days, 4 days and 6 days.

<Insert Figure 5 here>

Figure 5. Spot market revenue for different booking periods.

Figure 5 Alt text. The figure depicts the variations in the revenue for spot market demand, while considering different booking periods of 2 days, 4 days and 6 days.

Table 3 provides the optimal number of containers of different dimensions allocated to contract shippers for each origin-destination pair in the given case study. The first section of table 3 presents the number of containers for the two origin-destination pairs: (Singapore, Colombo), (Xiamen, Colombo). Similarly, in the next two sections of table 3, the number of containers is presented for origin-destination (Colombo, Singapore), (Xiamen, Singapore) and (Colombo, Xiamen), (Singapore, Xiamen) respectively. Thus, the optimal booking limit for contract containers and spot containers can be achieved by solving the slot allocation model. Based on the limits the shipping company can accept or reject the booking. The revenue from contract market, the empty container repositioning cost and the container leasing cost are depicted in figure 3 considering different booking periods (days). The computational time to solve the instances generated for different time periods varies between 57 seconds to 1 min 20 seconds. Next, figure 4 represents the market revenue for the ad-hoc containers i.e., for spot shippers with different booking periods. After finding the booking limits, the shipping manager accepts or rejects the request and all the information is shared among all the agents. All of these processes, as well as the decisions taken, are recorded and saved in the knowledge base agent for future use.

< Insert Table 3 here >

Table 3. Number of optimal contract containers of different dimensions.

## 6. Managerial implications

This study has various implications in the marine supply chain. Our study is prompted by the growing trend of digitization in the marine supply chain, as well as the usage of a variety of communication platforms and the huge amount of manpower in the container booking process. A multi-agent container booking system is a new way to assist enterprises in the supply chain to enhance efficiency and stay up with the digitalization trend. The maritime shipping industry can benefit from this framework by streamlining operations, collaboration, and communications with a global workforce. The automated processes of the system significantly can decrease the expenditure of the companies occurred in the manual processes. Executives of prominent maritime organizations can generate benefit from the suggested multi-agent system, because the seamless communication between the system's various complicated stakeholders will enhance efficiency and profit. Hence, the proposed approach will result in a scalable, distributable, and flexible system that provides seamless integration of all operations, real time information interchange, reduction in operational costs, and ease of deployment.

## 7. Conclusion

The procedure of booking a container is complicated and involves a number of different agencies. Considering the complexities to deal with, this paper presents a multi-agent framework for a unified container booking system. To optimize all the activities of the system, nine independent agents are being used. The autonomous agents, such as, customers, suppliers, shippers, second-tier forwarder, first-tier forwarder, and shipping line are all brought together on a single platform for real-time and faster information interchange. Internal and external conflicts can also be handled by these agents while keeping long and short term goals in mind. This study also provides a decision support model using which the decision regarding accepting or rejecting the booking can be taken. To decide which booking is to be taken, a container slot allocation model is introduced considering market segmentation into contract and spot shippers. The model also considers different type of containers like dry, reefer and empty containers. Hence, the multi-agent framework with the container slot optimization model will boost efficiency and efficacy in the maritime industry. In future, the multi agent architecture can be incorporated into other major operations of maritime shipping such as routing, scheduling, berth allocation and bunker fuel optimization.

**Disclosure statement**

The authors have no conflicts of interest.

**Data availability statement**

The data that support the findings of this study are available from the corresponding author, J. Mandal, upon reasonable request.

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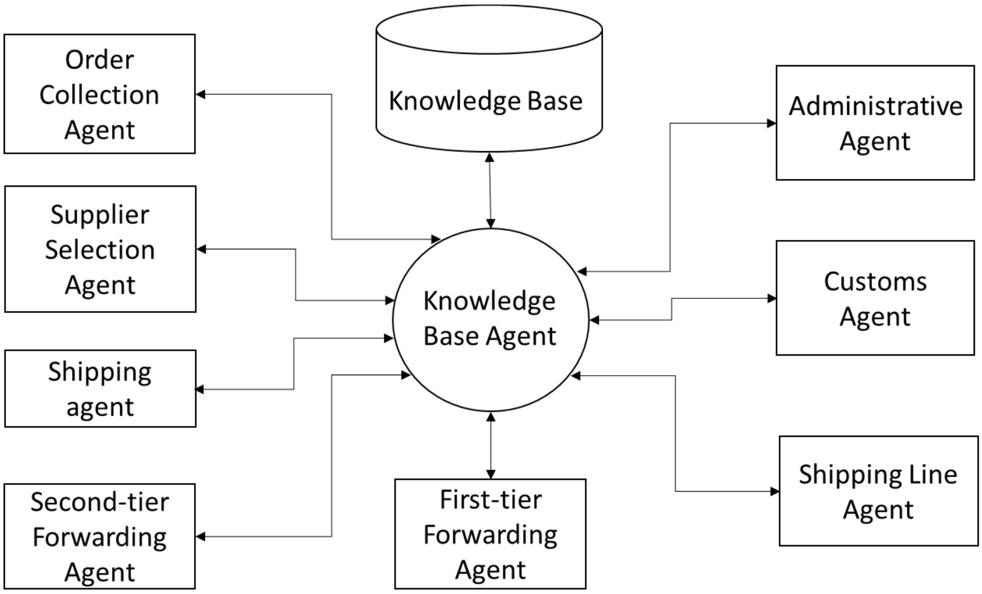


Figure 1. Multi-agent architecture.

Figure 1 Alt text. The figure depicts the multi-agent architecture for liner shipping container booking involving supplier selection agent, order collection agent, shipping agent, second-tier forwarding agent, first-tier forwarding agent, knowledge base agent, shipping line agent, customs agent and administrative agent. All of these agents collaborate with one another.

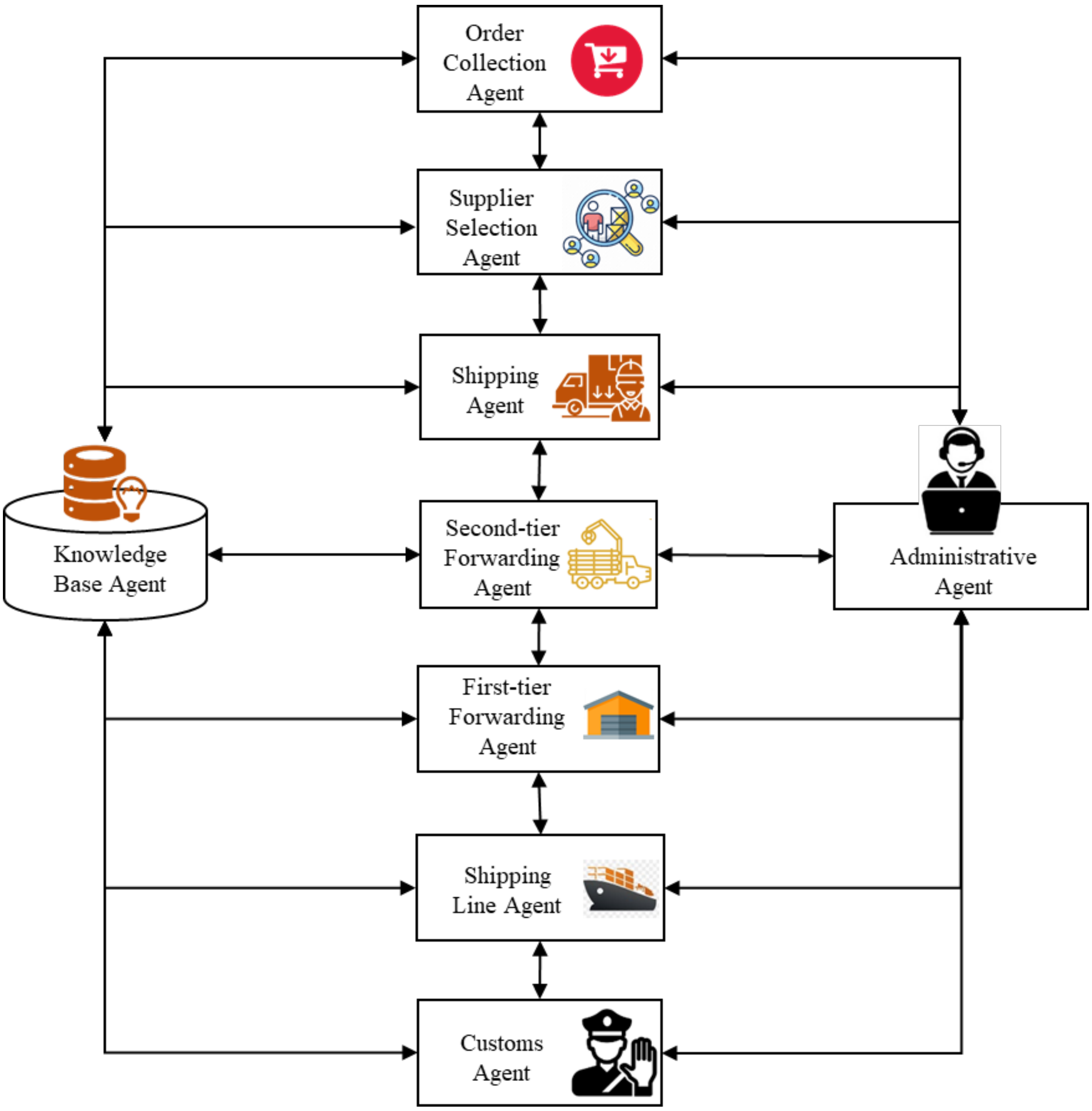


Figure 2. Container booking scenario and interaction between agents.

Figure 2 Alt text. The figure shows the container booking process and how the agents interact with each other.

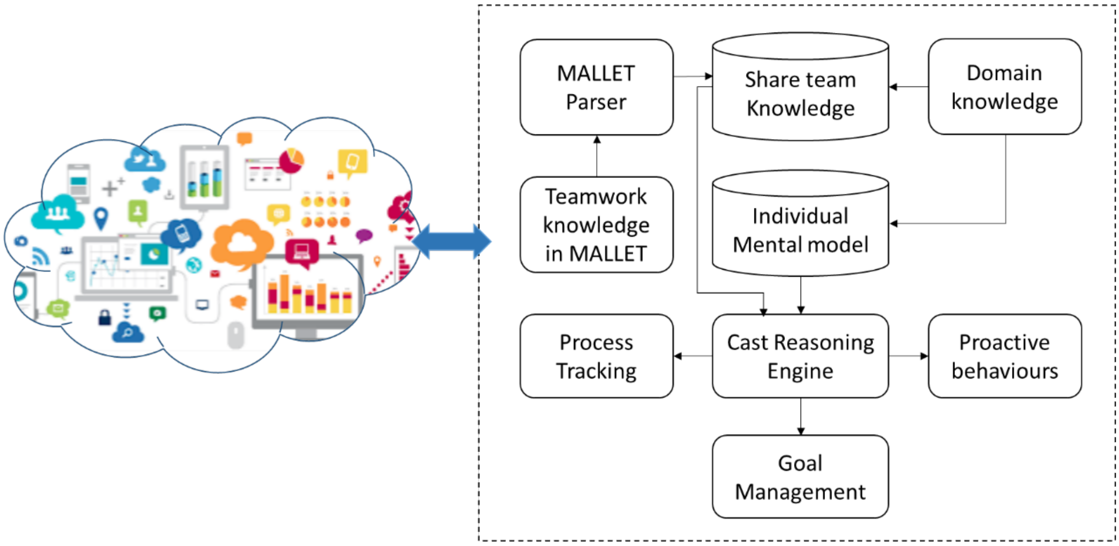


Figure 3. CAST architecture for multi-agent system

Figure 3 Alt text. The figure represents the CAST architecture for the proposed multi-agent system. The agents communicate with one another utilizing the Multi-agent logic language for encoding Teamwork (MALLET), which is an agent communication language**.** MALLET will be used by the agents in the system to promote effective and exact communication among them and it is interpreted by Collaborative Agents for Simulating Teamwork (CAST).

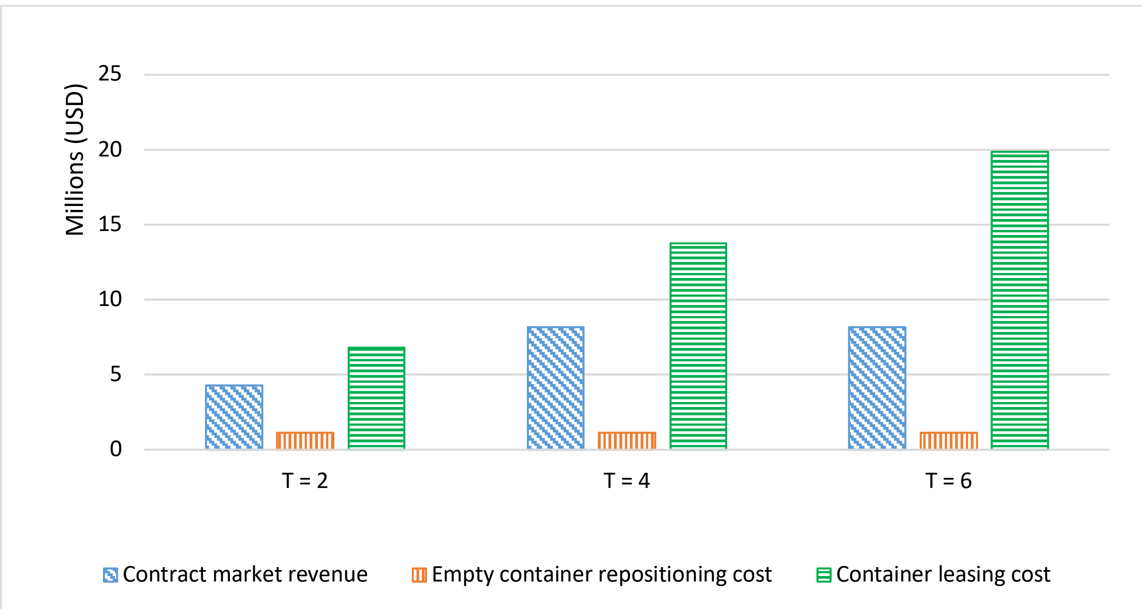

Figure 4. Contract market revenue, empty container repositioning cost and container leasing cost for different booking periods.

Figure 4 Alt text. The figure shows the variations in the revenue for contract demand, empty container repositioning cost and container leasing cost while considering different booking periods of 2 days, 4 days and 6 days.

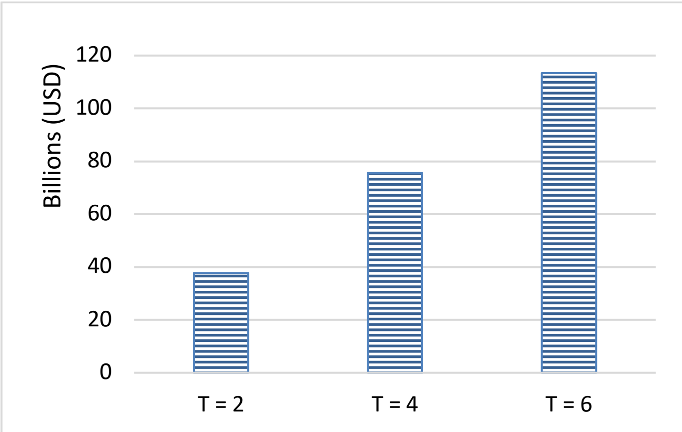


Figure 5. Spot market revenue for different booking periods.

Figure 5 Alt text. The figure depicts the variations in the revenue for spot market demand, while considering different booking periods of 2 days, 4 days and 6 days.

Table 1. Volume and weight of different type of containers.

| Containers | Weight (ton) | Volume (TEU) |
|---|---|---|
| 20’ dry | 17 | 1 |
| 20’ reefer | 17 | 1 |
| 40’ dry | 23 | 2 |
| 40’ reefer | 23 | 2 |
| 40’ high cube | 23 | 2.25 |
| 40’ high cube reefer | 23 | 2.25 |

Table 2. Waiting time at the ports at different scenarios of port congestion.

| Port | Uncongested | General | Heavily congested |
|---|---|---|---|
| Colombo | 0 | 1 | 2 |
| Singapore | 0 | 2 | 3 |
| Xiamen | 0 | 2 | 4 |

Table 3. Number of optimal contract containers of different dimensions.

| **Colombo** | 20’ dry | 40’ dry | 40’ high cube | 20’ reefer | 40’ reefer | 40’ high cube reefer |
|---|---|---|---|---|---|---|
| Singapore | 450 | 450 | 400 | 450 | 400 | 321 |
| Xiamen | 450 | 100 | 400 | 100 | 400 | 450 |
| **Singapore** | | | | | | |
| Colombo | 450 | 450 | 400 | 100 | 400 | 100 |
| Xiamen | 100 | 100 | 400 | 100 | 400 | 100 |
| **Xiamen** | | | | | | |
| Colombo | 450 | 450 | 400 | 450 | 400 | 450 |
| Singapore | 450 | 450 | 400 | 262 | 400 | 262 |