Combined Modeling with Multi-Agent Systems and Simulation: Its Application to Harbor Supply Chain Management

Dong Won Yi
Strategic Management Div., LG-EDS Systems, Seoul, Korea dwyi@lgeds.lg.co.kr

Soung Hie Kim
Graduate School of Management, KAIST, Seoul, Korea seekim@kaist.ac.kr

Nak Hyun Kim
Strategic Management Div., LG-EDS Systems, Seoul, Korea nakhkim@lgeds.lg.co.kr

Abstract

This paper presents a method for modeling the dynamic behavior of harbor supply chains and evaluating strategic and operational policies of the proposed harbor supply chain by applying multi-agent systems and simulation.

The multi-agent systems modeling represent business entities as agents and the involved information and material flows with proposed coordination method for collaborating among agents. The simulation model is applied to quantifying the flow of supply chain, information and material flow, and conducted to simulate the global harbor supply chain operations, and determined which strategic and operational policies are the most effective in smoothing the variations in the supply chain.

1. Introduction

The supply chain is a network that performs the procurement of raw material, the transportation of raw material to intermediate and end products, and the distribution of finished products to retailers or directly to customers. These network, which usually belong to different companies, consist of production plants, distribution centers, and end-product stockpiles[8].

Supply chain management creates a virtual organization composed of several independent entities with the common goal of efficiently and effectively managing all its entities and operations, including the integration of purchasing, demand management, new product design and development, and manufacturing planning and control[13]. However, this perspective on supply chain management focuses on the manufacturing industry

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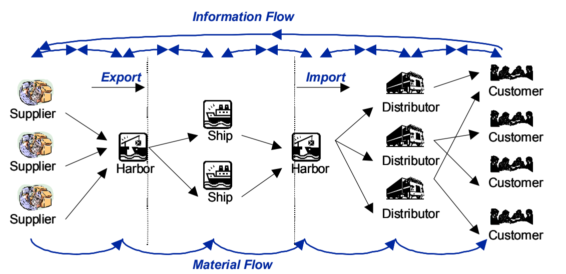
and has little to do with the other industry(e.g. wholesaling or harbor industry).

For the modeling and analyzing both the structure and processes of an enterprise, multi-agent systems is developed and implemented in other research domain[11, 18]. Multi-agent systems is a collection of, possibly heterogeneous, computational entities, having their own problem-solving capabilities and which are able to interact in order to reach an overall goal[10]. Lin et al. [9] suggests a multi-agent information systems for supply chain network and simulates the performance of order fulfillment process. Sikora and Shaw[17] presents a multi-agent framework for agent coordination, which characterizes the different control strictures that are possible in a multi-agent systems and leads to a useful taxonomy of the interdependencies among the agents and a taxonomy of the coordination mechanisms.



[Figure 1] The schematic diagram of harbor supply chain

Generally, the harbor and maritime industry has been an area for simulation. Due to the costs and complexity of both harbors and vessels, the use of simulation has been justifies in this area from many years. There is a wide range of papers[14, 16] devoted to different aspects of harbor container terminal simulation. However, there is growing need in developing global supply chain perspectives for the management and control of harbor and maritime transportation[Figure 1].

The purpose of this paper is to present modeling and simulation methodology in the harbor industry. Supply chain that satisfies the overall operations and logistics policies are proposed for global supply chain and logistics. In order to sustain competitive advantage, it is not enough to construct efficient supply chains. They must have the flexibility to modify and redesign their supply chains to respond to sudden economic changes. Multi-agent systems modeling and simulation offer promise in respect to these challenges. The objective of the multi-agent systems represents business entities as agents and the involved information and material flows with proposed coordination method for collaborating among agents. The simulation model is to determine which strategic and operational policies are the most effective in smoothing the variations in the supply chain.

The remaining of this paper is organized as follows. Chapter two presents the harbor supply chain and its resources and operations. Application of multi-agent systems to the modeling and design of harbor supply chain is proposed in chapter three. Chapter four describes the Markov decision processes for coordination among agents. The simulation and analysis of harbor supply chain is described in chapter five. Finally, conclusions and further researches are presented in chapter six.

2. Literature Review

Generally, the seaport operations in the management of harbor are berth allocation, yard

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planning, storage planning, and logistics planning of container operation. These can be analyzed by simulation that is a powerful tool for evaluating the performance of a proposed system and choosing an appropriate design before actually implementing the solutions. For the design and analysis of supply chain operation, simulation based approaches are summarized as follows: (1) simulation approach only applied to harbor operation, (2) simulation with analytic model, (3) simulation with object-oriented approach, and (4) simulation with multi-agent system. As modeling approach is driven by the nature of the inputs and the objective of the study, it is important that the representation and analysis of the supply chain dynamics.

On simulation approach only applied to harbor operation, recently, Razman and Hussain[16] develops a simulation model to assist in the management and operation of Kelang container terminal which includes berth allocation, crane and prime movers assignment using Arena simulation software. For managing the Riga harbor container terminal, a modeling and simulation methodology, Nevins et al. [14] simulates detailed processes for ship operations at the seaport, (1) docking at the berth, (2) calling forward appropriate cargo items, and (3) loading and unloading cargo items. The use of simulation in supply chain, Towill et al. [6] use simulation techniques to evaluate the effects of the various supply chain strategies on demand amplification.

Beamon[3] suggests category of the supply chain modeling approach; (1) deterministic analytical models, in which the variables are known and specified, (2) stochastic analytical models, where at least one of the variables in unknown, and is assumed to follow a particular probability distribution, and (3) simulation models. The main drawback of analytical models is the fact that most models only take few variables into account and numerous constraints have to be satisfied before results can be applied in practice. Combined approaches with simulation are, recently, developed for design and analysis of integrated multi-echelon system.

Bruzzone and Signorile[2] outlines the classification of current harbor simulation researches (1) terminal operation study, (2) training system design, (3) military operations study, and (4) building port simulators, and develops simulation model with the use of genetic algorithms to perform dock planning and yard planning. Fuzzy modeling and simulation of a supply chain in a uncertain environment is suggested by Petrovic et al. [5] to obtain an acceptable delivery performance at a reasonable total cost for the whole supply chain. Van der Vorst et al. [12] analyze a food supply chain with the concepts of business processes and develops a simulation model to support decision making when redesigning a supply chain.

For enabling the designer to experiment with different alternatives by assembling a set of predefined building blocks, simulation with object-oriented approach was suggested in order to structured design and analysis of integrated supply chain. A simulation model for container terminal system analysis is developed by Yun and Choi[19] who considers as the hierarchy of the container terminal system and develops a simulation using and object-oriented approach and object-oriented simulation software(e.g., SIMPLE++). Alfieri and Brandimarte[1] suggests an object modeling approach for the performance evaluation of integrated

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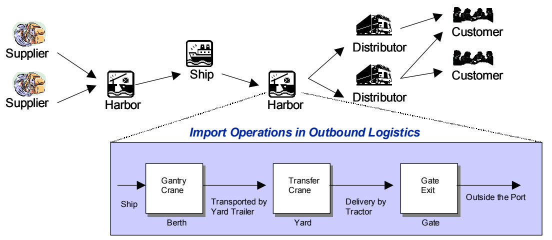
supply chains and presents a object model of a multi-echelon inventory management system using object-oriented programming language(e.g., MODSIM).

Because complex interaction between entities and the multi-tiered structure of supply chains, it make difficult to utilize analytical approaches. The simulation provides an effective pragmatic approach to detailed analysis and evaluation of supply chain design and management alternatives. However, there are two major problems associated with building customized simulation models: (1) they take a long time to develop and, (2) they are very specific and have limited reuse[11]. Therefore, multi-agent system that is a flexible and reusable modeling and simulation framework that enables rapid development of customized decision support tools for supply chain management was suggested and applied to other industry[18]. Multi-agent systems is a collection of, possibly heterogeneous, computational entities, having their own problem-solving capabilities and which are able to interact in order to reach an overall goal[10]. On the multi-agent system for supply chain management, Lin et al. [9] suggests a multi-agent information systems for supply chain network and simulates the performance of order fulfillment process.

A performance measure is used to determine the efficiency and/or effectiveness of an existing system, or to compare competing alternative systems. Performance measures are also used to design proposed systems, by determining the values of the decision variables that yield the most desirable level(s) of performance. For performance measurement in the supply chain, Beamon[4] emphasizes a supply chain measurement system and identifies the use of resources, the desired output, and flexibility as vital component to supply chain. To coincide with strategic and operational policy of the supply chain, each type of performance measure can allow the interactions among the measures or can at least ensure a minimum level of performance. In this paper, we make use of order fulfill rate and on-time delivery for output performance measure, volume and delivery flexibility for flexibility performance measure, and resource utilization level for resource performance measure

3. The Harbor Supply Chain: Resources and Operations

A harbor is a place where cargo is loaded onto the ship, unloaded from the ship, and stowed on the pier where the receipt and delivery of freight happen. Harbor management system consists of ship operation system, cargo moving system, storage systems, receipt and delivery systems, gate operation systems, and management and operation information system.



[Figure 2] The import operation in the outbound logistics of harbor supply chain

For the import flow in outbound logistics described in [Figure 2], ships arrive at the port, receive the service at the berth, and then de-berth after completing the activities of the unloading and loading the containers. Containers are unloaded by the gantry

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cranes from the ships, and then transported by yard trailer to the yard. At the yard, the transfer crane load/unload the container to the yard and the tractor moves the container to the gate for outside the port. For the export containers, the reverse process applies. The resources which needed to operate the harbor management system, are cargo handling equipment, berthing facility, computer system, port labor, etc [7]. In addition, the operational policies of container terminal consists of berth allocation, yard planning, stowage planning, and logistics planning[19]. Berth allocation controls the loading and unloading of a ship's container. Yard planning assigns optimal allocation of storage areas for import, export, and transshipment containers. Stowage planning assigns storage locations to the containers in the bay of the ship. Logistics planning assigns and coordinates the operations of the container handling equipment such as gantry cranes, transfer cranes, and yard tractors in the transportation of containers between the ship's bay and the container yard. Therefore, full utilization of resources and proper management of operational policies are major concern in the harbor supply chain. In this paper, the simulation model develops for operational policies, e.g., berth allocation and logistics planning. The berth allocation policies simulate the movement of the ship to the berth and assignment of the ship to the berth with certain rule. The logistics planning policies simulate the assignment of the cranes to the ship at the berth with based on a number of rules.

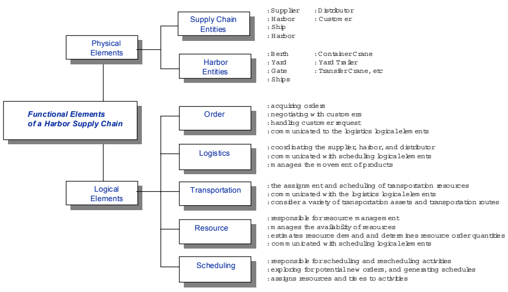
Generalized from the variety and complexity of supply chain, the characteristics of the supply chain are not only distinguished by the physical connections(i.e., the number of tiers, the number of nodes, and the types of participants) but also by the operations, objectives, and other attributes. The important attributes include (1) objective in business entity, (2) value-added business process, (3) objective in business process, (4) ownership in business process, (5) business entity, and (6) interdependency. Using these attributes to contrast with manufacturing supply chain, we identify that harbor supply chain differentiated by (1) product characteristics, (2) logistics characteristics, (3) strategic and operational policies. The harbor operation determines the main part of harbor supply chain and it has concurrently characteristics of inbound and outbound logistics(import and export operations). In addition, as the harbor supply chain has not manufacturing equipment but logistics equipment for transport the ordered product, the product is not manufactured or assembled but delivered to customers. Therefore, the harbor supply chain emphasizes the logistics-related operational policies based on order fulfillment, which is the essence in harbor supply chain.

In this paper, the simulation model develops for berth allocation and crane assignment policies. The berth allocation policies simulate the movement of the ship to the berth and assignment of the ship to the berth with certain rule. The crane assignment policies simulate the assignment of the cranes to the ship at the berth with based on a number of rules.

4. Multi-Agent Systems Modeling to Harbor Supply Chain

A Supply chain is composed of several autonomous or semi-autonomous business entities that can be viewed as agents[9]. Each business entity has its capability and capacity and can be assigned to or take certain types of tasks, according to its organizational roles. These capability, capacity, and organizational roles can be modeled as agents. Multi-agent systems focus on the coordination and the communication among agents to collaboratively accomplish tasks. Each agent is responsible for one or more activities in the supply chain and each interacting with other agents in planning and executing their responsibilities.

Based on various designs for the multi-agent systems in the literature[9, 10, 11, 15, 17, 18], we designs a multi-agent systems modeling as two kinds of agents: physical agents and logical agents[Figure 4]. A physical agent represents tangible existing objects, such as a ship, harbor. A logical agent represents a logical object with a information function, such as logistics agent, order agent, etc.



[Figure 4] The Functional Elements of a Harbor Supply Chain

The business entities can be represented as physical agents, while logical agents are used for controlling actions for material movement and information flows. The logical agents are described as follows in [Figure 5]:

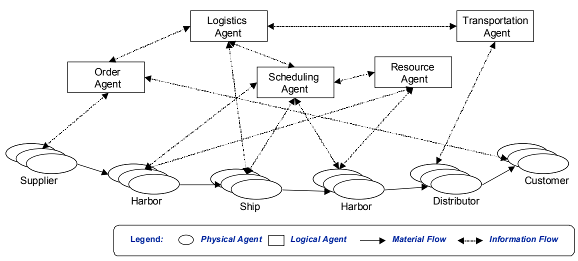
- Order Agent: This agent is responsible for acquiring orders from customers; negotiating with customers about prices, due dates, and the like; and handling customer request for modifying or canceling their orders.

- Logistics Agent: This agent is responsible for coordinating the supplier, harbor, and distributor to achieve the best possible results with scheduling agent, including on-time delivery, cost minimization, and so forth. It manages the movement of products or materials across the supply chain from the supplier of products to the customers.

- Transportation Agent: This agent is responsible for the assignment and scheduling of transportation resources to satisfy inter-harbor movement requests specified by the logistics agent. It can consider a variety of transportation assets and transportation routes in the construction of its schedules.

- Scheduling Agent: This agent is responsible for scheduling and rescheduling activities in the harbor, exploring for potential new orders, and generating schedules.

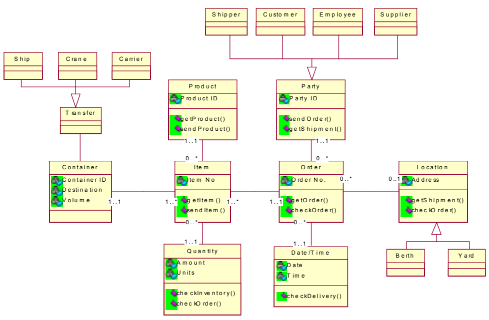
- Resource Agent: The resource agent is responsible for resource management to minimize costs and maximize delivery. It dynamically manages the availability of resources so that the schedule can be executed. It estimates resource demand and determines resource order quantities. This agent generates purchase orders and monitors the delivery of resources.



[Figure 5] The Interaction among Physical and Logical Agents

The interaction of these agents enables the flows of materials and information within an entity and to other entities that are immediately adjacent to it in the supply chain. To actual design and analysis, object-oriented modeling language, Unified Modeling Language managed by the Object Management Group, is selected. UML class diagram [Figure 6] for order information shows the association and inheritance among object class, and the attributes and methods for each object class.

The current prototype is developed on a network of PCs. The main development language is JAVA. The graphical interface for customer services is developed using JDK swing package. Communication among agents is realized using TCP/IP protocol and the inter-agent messages are formatted in KQML format . The current implementation is being developed initially in the form of a simulation.



[Figure 6] A Class Diagram for Order Information

5. Agents Coordination with Markov Decision Process

To optimize performance, supply chain must operate in a coordinated manner and coordinate the revision of plans or schedules across the supply chain. The ability to manage supply chain so that the timely dissemination of information, accurate coordination of decisions, and management of actions among people and systems is achieved ultimately determines the efficient, coordinated achievement of supply chain goals[15].

Coordination is concerned with managing the interaction among agents. Coordination aims at providing the most suitable negotiation mechanisms for the effective design and development of MAS, where active components(e.g., agents) communicate, synchronize, cooperate and compare within simulation environment. There is coordination between physical and information flow among business entities, coordination of operational policies between business entities.

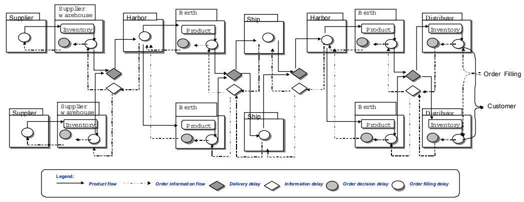
Using this Markov decision's recursive relationship, the solution procedure moves backward period by period until it finds the optimal policy in a finite number of iterations. The representation of rewards allows any number of criteria with their own reward values. As the reward structures correspond to different criteria, a linear combination of criteria(e.g., $w_1 output + w_2 flexibility + w_3 resource$) is used. Through measuring each type of criteria in agent, we achieve adaptive behaviors of the agent and obtain a performance measures in the supply chain. For performance measurement in the supply chain, Beamon[4] emphasizes a supply chain measurement system and identifies the use of resources, the desired output and flexibility as vital component to supply chain. To coincide with strategic and operational policy of the supply chain, each type of performance measure can allow the interactions among the measures or can at least ensure a minimum level of performance. In this paper, we make use of fill rate and on-time delivery for output performance measure, volume and delivery flexibility for flexibility performance measure, and inventory level for resource performance measure

As the agents have their individual performance measures, π_i (which is a combined measure $w_1 output + w_2 flexibility + w_3 resource$), the designing a synthesis function is the crucial problems in design a multi-agent systems. The synthesis function is how the individual sub-goals of the agents or their performance measures are related to the performance of the system as a whole. Sikora and Shaw[17] identify three Important types of synthesis functions, (1) Competitive synthesis, (2) Additive synthesis, (3) Cooperative synthesis. In this case, we adopts a cooperative synthesis, π = $\Phi(\pi_1, \pi_2, ...\pi_n)$, which is appropriate for bottom-up design of multi-agent systems where existing agents with different functional or operational policies have to be integrated into a whole.

6. Simulation and Analysis of a Harbor Supply Chain

The harbor supply chain under study has ten ships, eight berths and sixteen cranes for import and export berth operations. Based on the type of ship, the priority assignment for berth allocation was implemented in order to improve the operations within the port. Priority assigned to the ships results in ship turnaround time. The ships that arrive at the port are handled at the appropriate berths.

Each berth has at most an allocation of three cranes. Since the cranes are located in serial order, they cannot cross or overtake each other. The assignment of the cranes to the ship at the berth is based on a number of rules. The first rule is a fixed crane assignment based on the given priority. The second rule is a sharing crane assignment when the ship is berthing. Sharing of cranes is thus allowed only between two berths adjacent to each other. For every ship, at least one crane is available for the loading and unloading activities to begin. The third rule is an available crane assignment based on the adjacent to other berth for loading or unloading.



[Figure 7] A Simulation Model for Harbor Supply Chain

[Figure 7] represents a simulation model for harbor supply chain. Based on the order fulfillment perspective, simulation model identifies not only the product and information flow, but also the delay of delivery, information, order decision, and order filling. The input parameters of the experiment are the number of entities, their association(i.e., the relation between one entity and another), and their properties(e.g., whether they have logistics capability); and the coordination strategy, which determines the information propagation depth upstream or downstream. These input parameters determine the configuration of the experiment in terms of the structure of the enterprise to be incorporated into the simulation model and the combination of policies and strategies.

The results collected from the simulation model include ship through-put, ship turnaround time,

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service utilization of berth, waiting time before berthing, length of queue, and time spent in the queue. The simulation model was run for the ten replications and the average was recorded to reduce the variation. The average of this simulation output is compared with the historical data to validate the model.

In views of the order fulfillment, the performance measures for harbor supply chains used in the experiment are the order cycle time, the order fulfillment rate, the tardiness based on committed date given by an order fulfillment entity, and the tardiness based on customer expected lead time(a measure of customer satisfaction in terms of delivering desired products at the right time) In addition, the simulation models analyze the performance of different port operations with multi-agent systems. The agents contain different methods for handling different strategic and operational policies, which are invoked by message passing in simulation. All agents of the same class(e.g., the logistics agent) have identical methods; their behavior is determined by incoming message. Enabling message passing to other agents, agents evolve to the best performance status and produce combined(π) and individual(π_i)performance measure.

7. Conclusions and Further Researches

In this paper, we presents the modeling and analysis of a dynamics of business processes and interaction between business entities in a harbor supply chain. We developed and implemented a multi-agent systems and simulation model to (1) describe a harbor supply chain network, its component, behaviors, and interaction, (2) represent business entities as agents and the involved information and material flows with proposed coordination method for collaborating among agents, (3) simulate a harbor supply chain for the choice of strategic and operational policy satisfied performance measures.

The developed model aids in the design of efficient, effective, and flexible supply chain, gives valuable insights into the modeling and analysis of harbor supply chain configurations, and facilitates coordinated decision-maker interaction to solve supply chain problems. Based on agent and Internet technology, it can be built a supply chain system to execute agents in heterogeneous, decentralized, and physically distributed environment

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