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Application of Multi-Agent Systems and Simulation to Harbor Supply Chain: The Order Fulfillment Perspective

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Abstract

This paper presents a method for modeling the dynamic behavior of harbor supply chains by applying multi-agent systems, and evaluating strategic and operational policies of the harbor supply chain by applying simulation. In views of the order fulfillment, this paper considers the order fulfillment process which starts with receiving orders from the customers and ends with having the finished goods delivered.

A harbor supply chain that satisfies the overall operations and logistics policies are proposed for global supply chain and logistics. 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 applied to quantifying the flow of supply chain, information and material flow, and conducted to simulate the harbor operations, and determined which strategic and operational policies are the most effective in smoothing the variations in the supply chain.

Keyword

Supply Chain Management, Multi-Agent Systems, Simulation, Order Fulfillment

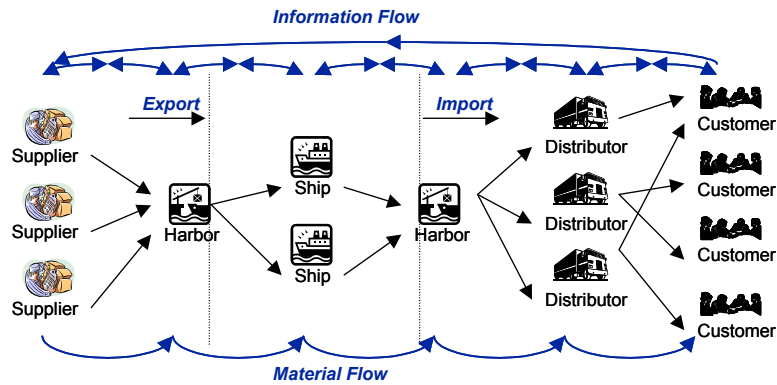
1. Introduction

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(Sabri and Beamon 2000).

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(Tan 2001). However, this perspective on supply chain management focuses on the manufacturing industry 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(Brandolese et al. 2000, Caridi and Sianesi 2000, Garcia-Flores et al. 2000, Shen et al. 2000, Swaminathan et al. 1998, Yan et al. 2000, Yan et al.2000). 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[Oliveira 1999, Ferber 1999]. It should be adaptable (1) to reconfiguration of different business processes, (2) integration of chain components into the supply chains. Lin et al. (1999) suggests a multi-agent information system for supply chain network and simulates the performance of order fulfillment process. Sikora and Shaw(1998) 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.

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 (i.e., Razman and Hussain 2000, Merkuryev et al. 1998, Nevins et al. 1998, Ramini 1996) 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].



[Figure 1] The Schematic Diagram of Harbor Supply Chain

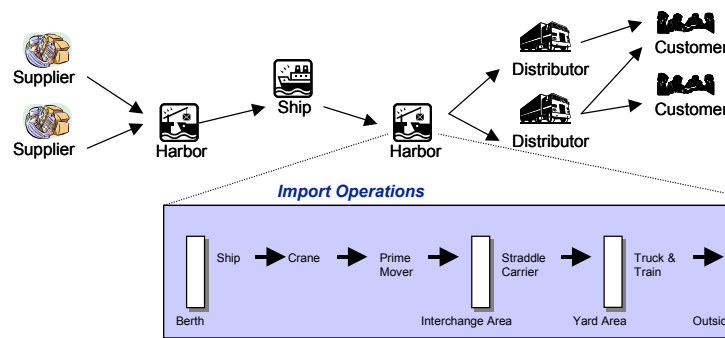
The purpose of this paper is to present modeling and simulation methodology in the harbor industry. Supply chain that satisfies the overall operations and logistics policies are proposed for global supply chain and logistics. In order to sustain competitive advantage, it is not enough to construct efficient 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. Section 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 section three. Section four describes the Markov decision processes for coordination among agents. The simulation and analysis of harbor supply chain is described in section five. Finally, conclusions and further researches are presented in section six.

2. 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. The resources which needed to operate the harbor

management system, are cargo handling equipment, berthing facility, computer system, port labor, etc(Yi et al. 2000). Therefore, full utilization of resources and proper management of operations are major concern in the harbor management system. To analyzing the complexity of harbor operations, simulation has been widely used and applied for the planning and management of harbor management(Nevins et al. 1998). For the import flow 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 cranes from the ships, and then transported by the prime movers to the interchange area before they are stacked in the yard. At the interchange area, the prime movers queue for the straddle carriers to stack the containers in the yard. For the export containers, the reverse process applies(Razman and Hussain 2000). The basic tasks in the management of a container are berth allocation, yard planning, storage planning, and logistics planning of container operations(Ramini 1996).



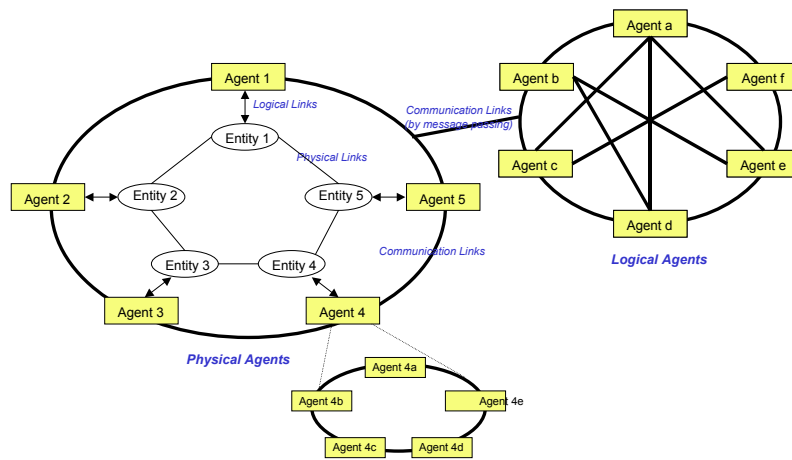
[Figure 2] The Harbor Operation in the Supply Chain

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.

3. Multi-Agent Systems Modeling to Harbor Supply Chain

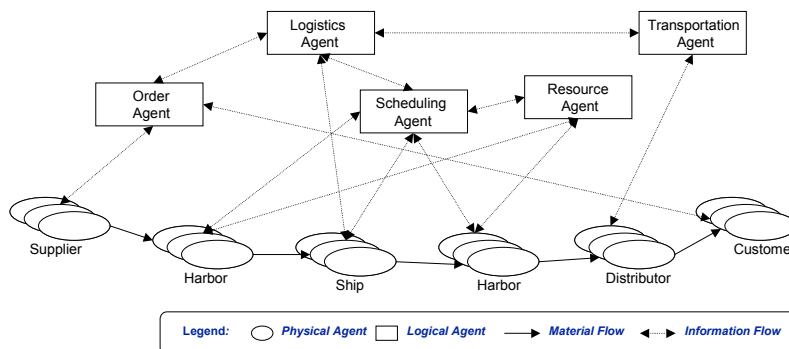
A Supply chain is composed of several autonomous or semi-autonomous business entities that can be viewed as agents(Lin et al. 1999). Each business entity has its capability and capacity and can be assigned to or take certain types of tasks, according to its organizational roles. These capability, capacity, 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. [Figure 3] shows physical and logical agents representation of a supply chain with multi-agent systems. The entities are modeled as agents, coordinates between agents *via* control, physical, and communication link for the involved information and material flows in supply chain.



[Figure 3] The Representation of a Supply Chain with Multi-Agent Systems

Based on various designs for the multi-agent systems in the literature (Shen et al. 2000, Garcia-Flores et al. 2000, Swaminathan et al. 1998, Oliveira et al. 1999, Ferber 1999, Lin et al. 1999, Sikora and Shaw, Fox et al. 2000), we design 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 an information function, such as logistics agent, order agent, etc.

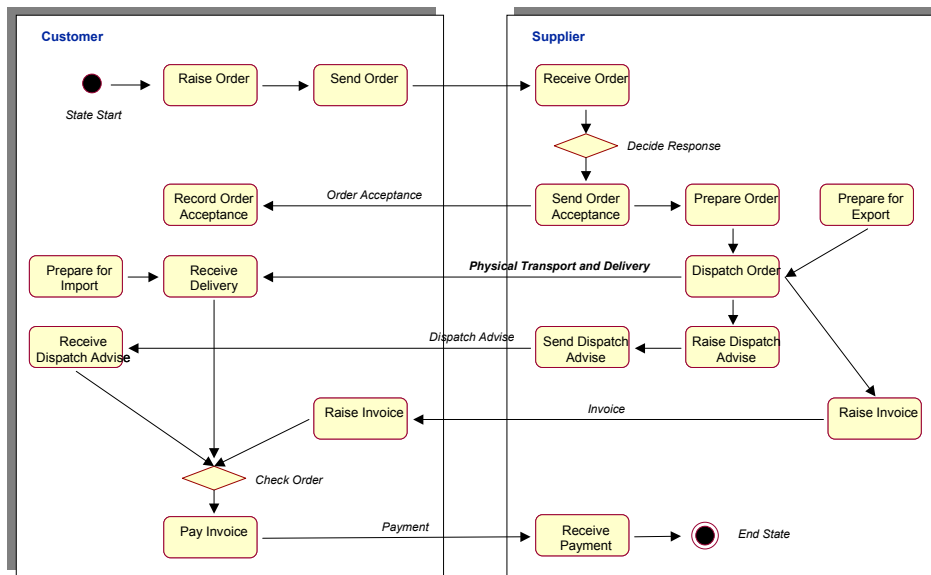


[Figure 4] The Interaction among Physical and Logical Agents

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:

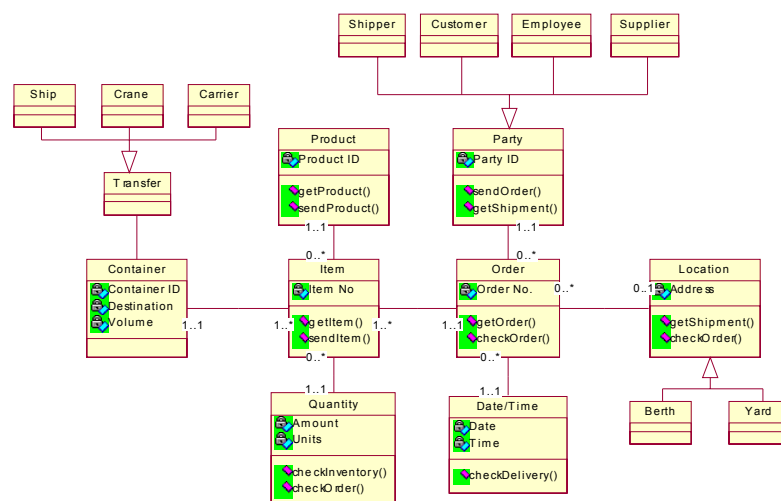
- Order Agent: This agent is responsible for acquiring orders from customers; negotiating with customers about prices, due dates, and the like; and handling customer request for modifying or canceling their orders. When a customer order is changed, that change is communicated to the logistics agent. When plans violate constraints imposed by the customer (such as due date violation), the order acquisition agent negotiates with the customer and the logistic agent for a feasible plan.
- 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. It assigns resources and start times to activities that are feasible while at the same time optimizing certain criteria such as minimizing work in progress or tardiness.
- 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. When resources do not arrive as expected, it assists the scheduler in exploring alternatives to the schedule by generating alternative resource plan.

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. For example, the order agent's activities that are involved order information described in [Figure 5] are performed as information passing between customer and supplier for the purpose of order fulfillment which refers not only to providing the customers with what they ordered and do it on time, but also to providing all related customer services.



[Figure 5] An Activity Diagram for Order Information between Customer and Supplier

To actual design and analysis, object-oriented modeling language, UML(Unified Modeling Language) managed by the Object Management Group (OMG), 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(Booch et al. 1998).



[Figure 6] A Class Diagram for Order Information

4. 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(Fox et al. 2000).

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.

Each agent has the states and rule for conversation as follows, (1) the arrival of messages expressing requests from other agents, (2) the current situation is evaluated, updating or creating a states, (3) an agent selects an appropriate rule for action. It can views as an Markov Decision Processes(MDP, Hillier and Lieberman 1990) which leads to finding the optimal policy. The current state i of the state and decision $d_i(R) = k$ when operating under policy R . The state i move to a new state j at the next observed time period, with the transition probability given by $p_{ij}(k)$. We define the reward(a real number) denoting the immediate utility of going from state i to state j by executing rule R . Since agent conversation meant to operate for indefinite periods of time, we use the theory of infinite horizon MDP. To compare policies, we use *the expected discounted reward*(W_{ik}) as the criterion to optimize. This criterion discounts future rewards by rate $0 \leq \alpha < 1$. Denoted by $V_i^n(R)$ the expected total discounted cost of a system starting in state i and evolving for n time periods;

$$V_i^n(R) = W_{ik} + \alpha \sum_{j=0}^M p_{ij}(k) V_j^{n-1}(R)$$

The value of a policy at any state i can be computed by solving this system of linear equations. A policy is optimal if $V_i(R_j) \geq V_i(R_{j+1})$ for all $i = 0, 1, \dots, M$ and $j = 1, 2, \dots$. Value iteration produces sequences of *n-step optimal value functions* V^n by starting with an arbitrary value for V^0 and satisfies the recursive relationship,

$$V_i^{n+1} = \max_k \left\{ W_{ik} + \alpha \sum_{j=0}^M p_{ij}(k) V_j^n \right\}, \quad i = 0, 1, \dots, M$$

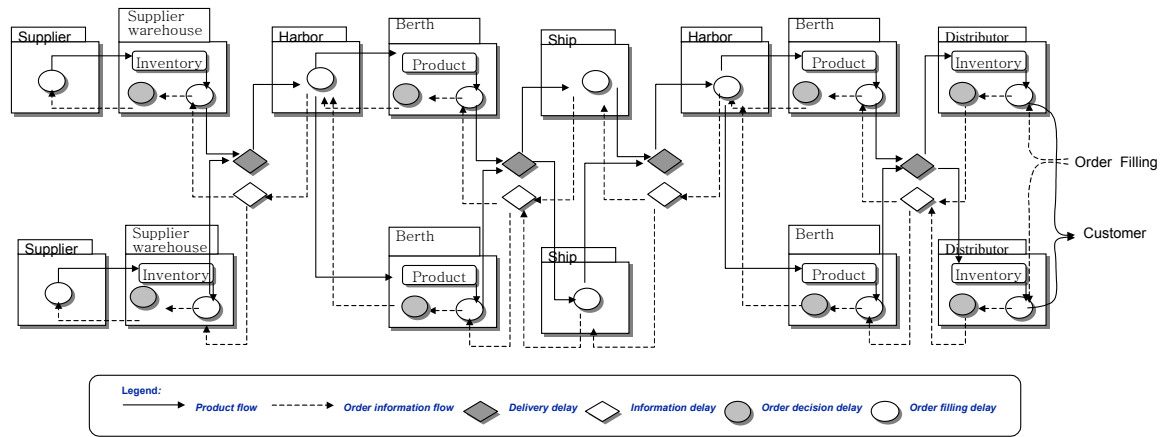
Using this recursive relationship, the solution procedure moves backward period by period until it finds the optimal policy in a finite number of iterations. The representation of rewards allows any number of criteria with their own reward values. As the reward structures correspond to different criteria, a linear combination of criteria (e.g., $w_1 \text{output} + w_2 \text{flexibility} + w_3 \text{resource}$) 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(1999) 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 $w_1 \text{output} + w_2 \text{flexibility} + w_3 \text{resource}$), 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(1998) identify three Important types of synthesis functions, (1) Competitive synthesis, (2) Additive synthesis, (3) Cooperative synthesis. In this case, we adopts a cooperative synthesis, $\pi = \Phi(\pi_1, \pi_2, \dots, \pi_n)$, 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.

5. 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. The constraints that a ship needs to satisfy to dock at the appropriate berth are as follows;

If (# of container > 30,000) or (berth.length > 1000 ft.)
 Berth.type = Container1 Berth
Else If ((# of container < 50,000) and (berth.length > 500ft.))
 Berth.type = Container2 Berth
Else
 Berth.type = (available) Container Berth

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, 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.

6. Conclusions and Further Researches

In this paper, we present 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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