An Agent-Based Model of Smart Supply Chain Networks

Tomohito Okada, Akira Namatame and Hiroshi Sato

Abstract A global industrial enterprise is a complex network of different distributed production plants producing, inventory, and distributing products. Agent-based model provides the approach to prove complex network problems of independent actors. A global economy and increase in both demand fluctuation and pressures for cost decreasing while satisfying customer services have put a premium on smart supply chain management. It is important to make risk-benefit analysis of supply chain design alternatives before making a final decision. Simulation gives us an effective approach to comparative analysis and evaluation of the alternatives. In this paper, we describe an agent-based simulation tool for designing smart supply chain networks as well logistic networks. Using an agent-based approach, supply chain models are composed from supply chain agents. The agent-based simulation tool can be very useful for predicting the effects of local and system-level activities on multi-plant performance and improving the tactical and strategic decision-making at the enterprise level. Specifically, this model can reveal the optimal method to ship the inventory on some situations which are demand fluctuation and network disruption. The demand fluctuation effects the inventory management. The network disruption restricts the logistics. This model evaluates supply chain management from the viewpoints of the amount of inventory, the way of shipping and cost.

Keywords Agent based model · Multi-Agents · Supply chain management · Logistics · Multi-echelon · Manufacturing · Risk management · Demand fluctuation · Network disruption · Supply chain cost

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1 Introduction

Supply chain and logistics networks become bigger and more complex as the result of globalization and new initiatives. This tendency makes it hard to manage the supply chain and to meet the demand for market. The collaboration of many independent contractors and suppliers is necessary to meet the demand for market. The company having the supply chain should have the alternative strategic solution for their supply chain to continue their company. One of these solutions is to make not only one-plant manufacturing facilities but also multi-plant enterprise. This change gives the company many advantages which are the low cost raw materials, the flexibility of change the product, and the changing the network of product flow [1]. On the other hand, the supply chain network involves many actors and it is operated collectively. The logistic network, physical network of transportation, also forms an interconnected complex system where it affects the behavior of the supply chain network.

Many analytical methods for modeling and optimizing different scenarios in a multi-plant enterprise are proposed [2]. They discuss mathematical formulations for operation management in multi-plant industrial networks. These works propose the methods for solving the combined production and distribution scheduling problem in multi-plant environments by using mathematical programming approaches.

2 An Architecture of Agent-Based Supply Chain

Lee and Billington [3] provided an insightful survey of common pitfalls in supply chain management practices. Some studies provide that the relationships of market and supplier depend on factors of quality, delivery time, flexibility in contract, as opposed to the factor of cost. From the point of analytical, there are so many researches of inventory problems in multi-echelon supply chain. Svoronos and Zipkin [4] study a multi-echelon system which having multiple tiers in the supply chain. The multi-echelon system is assumed that the company manages the supply chain with centralized control.

Towill et al. [5] applied a simulation technology to the evaluation of the effect of different supply chain strategies under the situation of demand expansion. Swaminathan et al. [6] present a modeling and simulation framework for developing decision support tools for supply chain management. They develop a framework that has two basic elements: object modeling of supply chain flows and agent modeling of supply chain entities.

Just-In-Time (JST) philosophy changes the typical style in supply chain management. The supply chain is effected by this philosophy becomes globalization, use of third party, and reducing the lead-time. These trends reduce the cost in supply chain and give the company competitiveness against other company in the same market. The merits of the reducing lead time are the reducing the inventory and defective, the removing the waste, and the problems to be clear [7].

The disruption is the important elements in supply chain management. The disruption in supply chain gives significant cost to the company. The company that experiences the disruption in supply chain will face significant declines in sales growth, stock returns, and more [8]. The disruption in supply chain takes place the network problem. The player and relationship between players can be expressed to the node and link. Considering a supply chain as a network problem, a disruption means the shutdown of node or the cut of link.

Supply chains are defined as a collection of business centers through which products pass at various stages of completion from the provision of raw materials to final sales. A supply chain can make the products for markets and delivery it to the markets. The individual company in supply chain can only grasp the limited visibility situation of supply chain. This is difficult to make the demand estimation in each player. The players in supply chain depend on the information which is obtained by own. Their information may be different from the information by headquarter management. The amount of order is larger than the headquarter one. The more amplified the amount of order. These problems occur under the dynamically supply chain. As a result of these problems, each company makes incorrect demand estimations and the amount of inventory is larger than the one by correct strategy. This is the well-known Bullwhip effect [6].

One of the solutions proposed to deal with the bullwhip effect is to have information sharing across the companies in the supply chain. There are unique characteristics required for information systems that support supply chain management. First, they should be able to support distributed collaboration among companies. Second, a single company cannot manage multi-players in supply chain directly, but there are need to coordinate each company by autonomy. Toyota motor adopts the automation of each player for a part of removal of waste [9]. Third, It is required the high intelligence for strategy, planning, and flexibility adaptation. For these reasons, agent modeling is suitable to support the supply chain management.

Many kinds of supply chains exist in the real world. Most share some common elements. For example, within each supply chain, material flows from a raw material state to an end-user [10].

Multi-agent technology has many beneficial features for autonomous, collaborative, and intelligent systems in distributed environments, which makes it one of the best candidates for complex supply chain management. Agent-based modeling (ABM) is a suitable approach to analyze the system influenced by autonomous agents. The system behavior effected from the behavior of the player in the system and their interactions. The reason of this is that the agent-based model is made of decentralized agent and the network which is made by them. Generally speaking, agents have their own decision making. They can make decision under any situation without centralized management. They are able to change their decision in any environment.

A multi-plant enterprise is modeled as modular, decentralized, changeable agent networks. The network of like this enterprise has so many kinds of agent and so many amount of agent. In addition, all agents set their aim in their supply chain by oneself.

The agent-based model can be used to analyze different stages of the supply chain in order to define what could happen under different scenarios, in example if aid were not enough to supply the "demand", and therefore understand possible side effects or delayed consequences such as bullwhip effect, distorted information from one end of a supply chain to the other can lead to remarkable inefficiencies. In the case of the aid supply chain, inventory moves up in the chain and it fluctuates more with donations recollected and in the distribution centers creating a distortion on the demand information. The model is built to represent the flow of emergency goods, and how it is affected by the information feedbacks, that explain the presence of bullwhips effects on the chain at different periods of time depending on the initial stocks of good storage on the different parts of the chain and on exogenous variables.

The elements of the ABM system are involved with production and transportation of products. The structural elements follow as:

Factory Agents**:** Factory agent makes the inventory for the demand in supply chain network. When the downstream agent orders the inventory to the factory agent, the factory agent ships it to the downstream agent. The factory agent calculates the amount of product by the order data from downstream agent. If the amount of inventory in the factory is under the point of product, the factory agent makes the inventory.

Retailer Agents: A retailer agent consumes the inventory by customer. This agent has the parameter of demand which is unpredictability. This agent calculates the amount of the safety stock, the amount of order point, and the amount of order. When the inventory in this agent is under the order point, this agent orders the inventory to upper stream agent.

Distribution Center Agent: A distribution center agent is role of buffer of stock in supply chain. This agent reduces the inventory of supply chain and makes a flow of inventory effectively. When this agent receives the order of inventory from downstream agent, this agent ships it to the downstream agent. If the inventory in this agent is under the order point, this agent orders the inventory to upper upstream agent.

Inventory Control: These elements control inventory at a particular production element by considering inventory levels at that entity in the supply chain. The basic control strategy is (s,S) policy in which ordering is done when the inventory levels goes below *s* [and orders are placed so that inventory is brought up to *S*.

Links: The link means the transportation route. The links effect the management at each agent, and the calculation of cost. The reason is that the link has the parameter lead time. The lead time from ordering agents to the clients has two features. The one is the almost route to delivery under 1 day. This is the transportation by the land route. This transportation is used to delivery from factory to distribution center or from distribution center to retailer. The cost by the land route is higher than others. This transportation has been not developing yet by reason of this. Another is that the lead time is over one day. This transportation is mainly sea route. The sipping distance by sea route is so longer than the one of land route. This transportation can ship the so many amount of inventory and can decrease the shipping cost by the packed many inventory into one. The cost of transportation par one inventory is cheaper than the cost by land route. The sea routes develop for long ago by the reason that low cost, massive transportation, and simple to maintain the equipment (the land routes need to maintain the all load. But, the sea routes need to keep up the ports and the ships.).

A Multi-enterprise in ASEAN

Asia in the current age is always growing up as the result of globalization, outsourcing and new strategy. Global company builds the factory in these places and opens up a new market in Asia. Developing areas and development one exist at the same time.

In ASEAN areas, the Mekong River in land area is developed. The reasons of this, these areas are the central of South-East Asia of shipping route. The sea route is developed and traditional route. The transportation of ships are able to delivery many inventory, to cost is less cheap than land route, and to maintain only ship. But in these days, ASEAN countries become rich by economic development. They make the land route to ship the inventory. This purpose is to short the lead time. This trend makes the network complex.

Disruption in Supply Chain

In South-East Asia, there is so large damage resulting from floodwaters. Despite there are many damage by floods, there is very little anti-disaster operations that deal with floods[11]. We should consider the network disruption by the disaster. Disasters bring the network disruption to supply chain network. For example, disaster makes the shutdown of factory, distribution center, and market. The streets stop the out of transportation function. In supply chain network, these mean that the shutdown of the nodes and the cutting of the links.

3 Model and Simulation

This simulation is to reveal the way of election the client when the demand fluctuation occurs at retailer agent. This simulation runs 3 times. We use the average data of 3 simulations. Each simulation has 1500 steps (this simulation define that one day is four steps. So, 1500steps means about one year.). The model using for simulation is consisted of two structures. First, the agent model structure is made by four kinds of agents which are factory agent (FC), distribution center agent (DC), and retailer agent (RT). The factory agent makes products when the amount of their inventory is under the order-point parameter. Ordered by distribution center agent, the factory agent ships the inventory. The cost of production is $10,000. The distribution center agent manages the inventory flow. This agent stocks, orders and ships the inventory to related agent. This agent ship the inventory to retailer ordered it. When their amount of inventory is under their order-point parameter, the distribution center orders the shortage inventory. In the retailer agent, the inventory is consumed by customer. The profit of 1 product is $20,000. When the amount of inventory is under the order-point parameter, the retailer agent orders the inventory. The delivery cost is $25 per one inventory by one step between each agent. The store cost is $1 per one inventory by one step in all agents.

The location of agents in this model is from the real location. In the following we describe the agent location in Figure 1 and Table 1. The data of FC location are based on TOYOTA motors. The locations of DC are the international port in Southeast Asia and the new land route junction. The cities of RT are the large city in Southeast Asia[12][13].

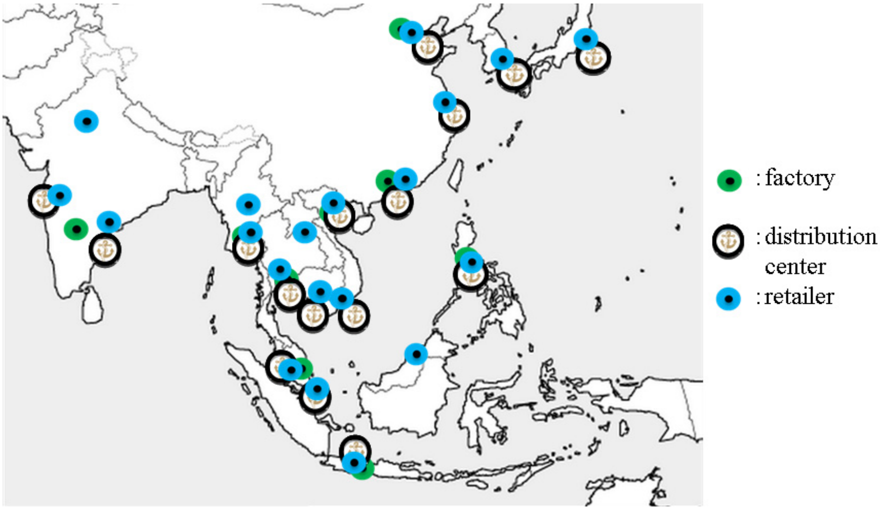

Fig. 1 The relation of the agents

Table 1 The city of agents

ID	FC	DC(departure)	DC(arrival)	RT
0	Kirloskar	Nhava sheva	Nhava sheva	New deli
1	Thilawa SEZ	Chen nai	Chen nai	Munbai
2	Bangkok	Thilawa SEZ	Thilawa SEZ	Chennai
3	KL	Leam chabang	Leam chabang	Nepido
4	Hanoi	sianukviles	sianukviles	Yangon
5	Jakarta	Ho chi minh	Ho chi minh	Bangkok
6	Hong kong	Hanoi	Hanoi	Vienchan
7	Beijing	KL	KL	Punonpen
8	Maynila	Singapore	Singapore	Ho chi minh
9	-	Jakarta	Jakarta	Hanoi
10	-	Beijing	Beijing	KL
11	-	Shanghai	Shanghai	Singapore
12	-	Hong kong	Hong kong	Jakarta
13	-	Maynila MITC	Maynila MITC	Burnai
14	-	Busan	Busan	Maynila
15	-	Tokyo	Tokyo	Beijing
16	-	land route Bangkok	land route Hanoi	Shanghai
17	-	-	-	Hong kong
18	-	-	-	Busan
19	-	-	-	Tokyo

The network in this model is constructed that the inventory flow is from FC to RT via DC.

Each agent makes transportation network with the link between each others. The link is drawn by the decision making of the agent. The agents make their decision by the calculation the order from the states of around them. The agents can see the parameter of next agents which are upper stream and down stream. They always calculate the safety stock (ss), the order point (op), and the amount of order (odr) to maintain their amount of stock[14][15]. These formulas of calculation follow as:

ss = service level × (the average of consume × lead time)
op = ss + (the average of consume × lead time)
odr = op - the amount of stock +(the average of consume × lead time)

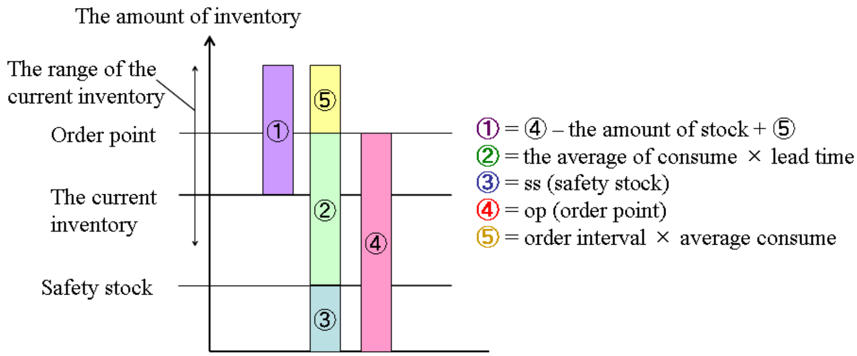

Fig. 2 The calculation of safety stock, order point and the amount of order

About the demand fluctuation in retailer, we use the two types of the demand value at the retailer in this model. These are based on the constant (cnst) and the log-normal distribution (lgnml). The reason of using the constant value is that comparing the way to elect the client under demand fluctuation with the only electing client simulation. We use the result of constant demand simulation as the standard elect client model. The constant demand in this model means that the same value through the all step. The value of consume by one step is 1. This means that the customer always buy one inventory at each of the retailer by steps.

When we simulate the model that the demand is based on the log-normal distribution, this value is given by

$$D_{t+1} = \mu + \rho_t D_t$$
$$\mu = 5$$
$$\rho_t = N(0, var),\ \rho_t \in (-1, 1),\ var \in (0.25, 0.5, 1.0)$$

The value of demand at the t step is Dt, The value of μ means the basement value of consume at the t step (This value is 5 in this simulation.), and the value of ρt represents the value from -1 to 1 following normal distribution (The average = 0, The variation is variable number among 0.25, 0.5, and 1.0 in this simulation.). Fig.1 shows the output of this formula on simulation. This means the value of demand fluctuation in this supply chain model (Simulation runs for 500 steps, the average of demand is 1.225).

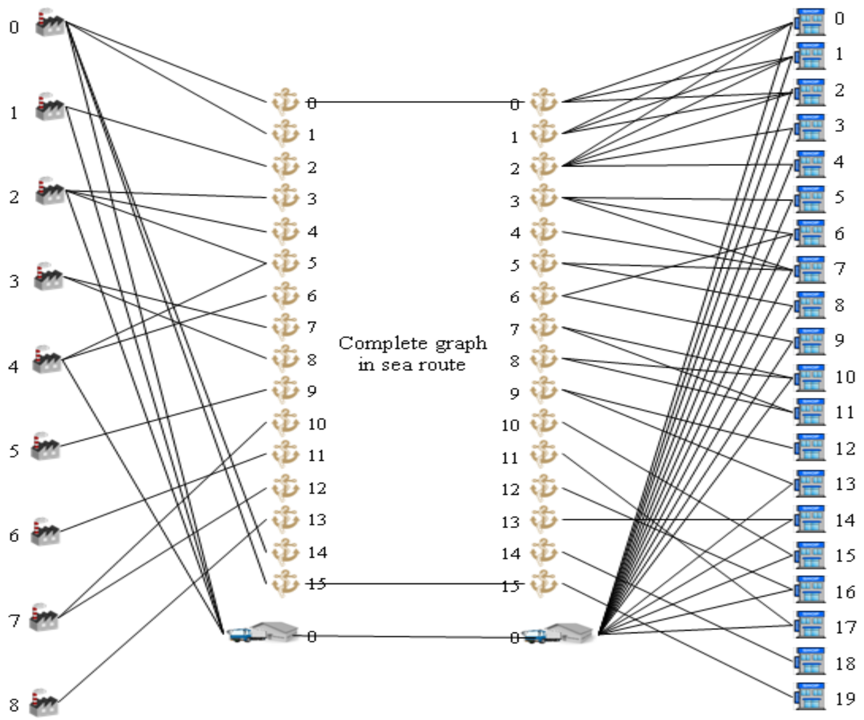

Fig. 3 The relation of the transport network

Another structure is the rule of how to decide making to manage supply chain network. In this model, this structure influences the choosing client for each agent. The clients which are elected by agents to order inventory have two features. First, the amount of inventory at the client change through time. Second, they are not the same lead time route in supply chain network. The agents have the three ways to elect their client. It is (1) random, (2) the same country, (3) the client which has the most inventory in all client candidate (shortest lead time), and (4) the client which has the shortest lead time in all client candidate (max stock). The agents which can deal with clients have this function. Figure 3 illustrates the shape of the network that the agents create. The numbers in the figure are the ID number of each agent.

Land Route: The junctions of land route are in Bangkok and Hanoi. The agents in continent are able to use the land route. In this model, the election of land route is one of the delivery methods. There are no agents to depend on the land route only in Southeast Asia. These land routes are built by a reference to [16] and [17].

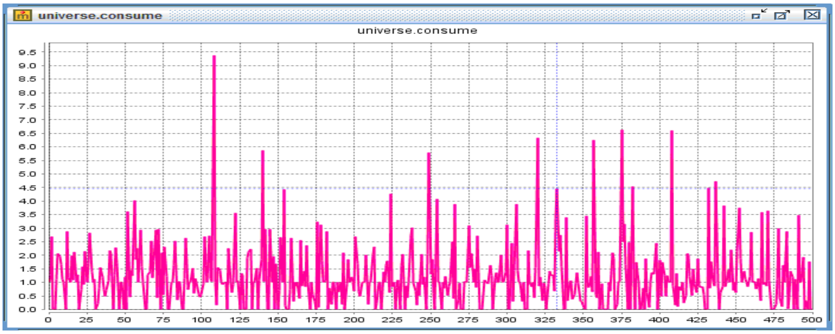

Fig. 4 The state of the demand Changes in market

Sea Route: The sea routes are 240 routes in this model (the number of the departure ports and the arrival ports are each 16 ports. This means that 16*15=240.). The all agent can use the distribution agent (port) to delivery the inventory. These values of transport dates by ship are based on the route via the Singapore port. The Singapore port is the most famous hub port in South-East Asia. So many ships go to their destination via Singapore port. The term of transport dates from arrival port to Singapore port is based on Jetro data. The term of transport dates from Singapore port to Arrival port is based on MAERSKLINE.

When the agent elect the client by the way of (1) random, (2) the same country, (3) the client which has the shortest lead time in all client candidate (shortest lead time), and (4) the client which has the shortest lead time in all client candidate (max stock) with the demand based on the function of Figure 4, the results of these simulation show table 2 and Figure 5.

Table 2 The average of stock and the probably of out of stock (OoS) at a retailer by simulation

Demand is constant		Random	Country	Lead time	Max stock
Only sea route	stock	3.0058	3.1922	2.7277	1.2775
	OoS (%)	14.86	0.09	43.92	66.68
Sea & land route	stock	3.3591	3.1708	2.2792	1.5001
	OoS (%)	13.76	1.39	51.62	64.20

Demand is based on log-norm		Random	Country	Lead time	Max stock
Only sea route	stock	4.3820	5.0035	3.4794	2.7260
	OoS (%)	15.07	1.68	42.96	48.86
Sea & land route	stock	4.8352	4.8876	3.0963	2.4181
	OoS (%)	3.42	3.10	44.73	51.88

In this model, the inventory calculates the profit and cost required at each location. When the transportations finish their role to delivery the inventory, the account calculates their profit and cost. The way to calculate is that accumulated profit = accumulated sales – accumulated cost. The Figure 5 shows the accumulated sales in each simulation by steps. We can see the difference of the increase rate in accumulated profit from figure 5.

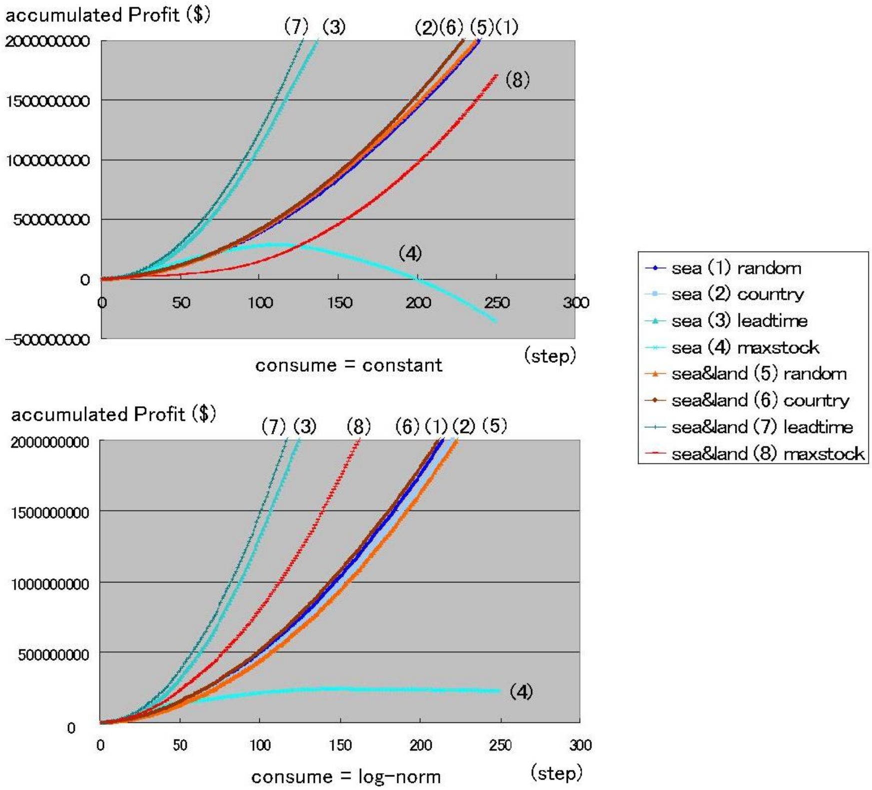

Fig. 5 The cost data of simulations

About the amount of stock, the ratio of the stock under the constant and log-norm distribution are no difference so much (Random:Country:leadtime:Max-stock≒4:4:3:2). When we choose the way to elect the max stock client, the amount of stock in all is the least in any other simulation. The reason is that two or three agents are working while changing and others are suspended. It is possible to reduce the amount of stock at the suspended agent. The way to reduce the amount of stock is to short the lead time of client.

About the out of stock, choosing the client with the way to elect the client randomly or the client in the same country, we can avoid out of stock better than other ways. The reason is the flexibility of choosing the client. The flexibility by random does not influence the previous decision making. The choosing new client which is not related previous client is the important element to make the network away from the previous influence most.

About the route, the results in 6 out of 8 simulations are that the amount of stock by sea route only is less than the one by sea & land route. Especially, the results under the demand based on log-norm distribution show that all network by sea&land route are less amount of stock than the one by sea route only.

About the cost, the result of “sea(1) and sea&land(5)”, “sea(2) and sea&land-(6)”, and “sea(3) and sea&land(7)” are resemble. “sea(4) and sea&land(8)” show the different lines. Choosing the client with the way to elect the client which has the shortest lead time in all client candidate (max stock), the profits under the constant demand are less than any other way. Especially, situation(4) is the least profit in all. The result of profit using the way to choose the max stock agent is that the value of profit under the log-norm distribution consume is more than the one under the constant consume. The reason is the difference in the average consumption. The average consumption under the log-norm distribution is more than the one under the constant. This value changes the result of the profit between these simulations. The way to get the biggest profit among all simulations is the choosing the client which has the shortest lead time in all client candidate (shortest lead time). The reason is that the short lead time decreases the cost of delivery and storage. When we choose the client which has the most stock in any other clients, the lead time is not the shortest in all.

4 Conclusion

These simulation results mean that the network made by the concept of short lead time is to reduce the amount of stock and cost, that we can avoid the out of stock at retailer by out of influence of previous client which is shortage stock (by random), and that we should make sure that a land route can also be used. We have some attention. The lead time by land route in real world is very short (The lead time by sea route is almost over 2 times of the one by land route). But the cost is very high. The problem which merit is better for the supply chain management depends on a making decision by manager.

5 Extension and Future Works

The proposed model in this paper is the application to help the decision making in the multi-plant supply chain problems. Especially, this model focuses the inventory flow from factory to retailer. If the model expands the region of flow, the future model is able to simulate the flow from row material to product in the customer hands. The future model which is made from this model can assist to make the supply chain management. The future model will be able to solute the optimal delivery route and location under various situations and the demand from the enterprise manager. When the future model get some function and expanded the data, this can correspond to demand fluctuation, disruption, and so many and different compromise plan.

This research reveals the potential of using the agent-based modeling for supply chain management. Decision making in supply chain network is effected of various types of agent, the amount of agent, and the relationship of each agents. The agent- based modeling approach is able to help the decision making to manage the supply chain under the dynamically network and environment. Considering unpredictability change and our request under the any situation, agent-based modeling approach reveals the optimal decision.

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