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Application of Agent-Based Simulation and System Dynamics to Control the Risk of Enterprises and Human Life

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Abstract

This paper proposes an application method of agent-based simulation and System Dynamics to control the destruction and disruption risk of an enterprise network. There always exists a risk of destruction and disruption and the risk is apt to synchronize in an enterprise network because the enterprise network is very weak and has uncertainty. Agent-based simulation and System Dynamics can easily make the simulation model of an enterprise network and realistically describe the uncertainty and variation of the model. This study, also, analyzes the effect of experimental models and provides advice to control it.

Keywords: Agent-based simulation, System Dynamics, Destruction, Disruption, Enterprise network, Uncertainty, Simulation model, Variation

1 Introduction

Human life has been determined by various factors and especially it depends on the economic support and social stability. Human psychology is constantly changing with condition of his/her own nation, society, and enterprise network because we live in a society with a highly developed material civilization. It, that is, is no exaggeration to say that human life counts on not a person's condition but the stability of his/her own network because the human's network risk influences immediately on his/her own. Human life, therefore, may become prosperous if the his/her own network is not run into danger and then the sustainability of the network is guaranteed. In order to enrich human life, an approach method in a network perspective removes the risk of destruction and disruption in a supply chain and then finds an alternative to guarantee the sustainability of an enterprise network.

In today's society, the fate of the firm is determined by changes in the country or companies, thousands of kilometers away from there, because the companies are ran by the outsourcing network which is diversely and intricately connected with each other through the spread of global supply chain. In this circumstance, human beings should prepare ample supply chain strategies and tactics to prevent unexpected events that occur unexpectedly to support a rich life.

In the 2000s, huge and various natural disasters have led to the crisis of the supply chain management and these difficulties are destroying human life. A worldwide freeze and natural disasters resulting from the earthquake that occurred in Japan, China, Haiti, Chile, and Iran, an oil leak in U.S. coast, a great flood in Pakistan, the smog caused by forest fires in Russia, a volcanic eruption in Iceland, and etc. gave a blow to the supply chain of corporations and then it greatly influenced human life.

Today, the crisis response and management skills of a supply chain are becoming the essential strategy for the survival of businesses at a time when uncertainty is accelerating. A method, therefore, is needed to control the risk of destruction and disruption in a supply chain including corporate networks in order to ensure continuously the human life. Also agent-based simulation and system dynamics is needed to optimize a supply chain.

Corporations which are included in the same network always regard its supply chain as working normally. The related enterprises, also, believe that they will always able to change the information desired each other and the network they belong will operate for ever to carry out business.

The problem of companies that carry out a business, which is caused by natural calamity or man-made mistake, is expressed as a word, disaster or risk. Dash et al. [1] defined disaster as “a breakdown in the normal functioning of a community that has a significant adverse impact on people, their livelihood and their environment, overwhelming local response capacity.” Risk was categorized into two groups, systematic risks and non-systematic risks [2]. Systematic risk is related to environmental factors that are unavoidable and non-systematic risk is related to factors that can be controlled to a large extent by an enterprise. This paper will approach the disaster in view or a risk of destruction (a few tiers are destroyed and then alternative tiers are needed because the resilience of the tiers is impossible) and disruption (a whole supply chain or a few tiers are temporarily delayed and then the resilience of the supply chain or the tires is gradually progressed) of an enterprise network (or a supply chain).

Realistically, a supply chain has a risk of destruction and disruption caused by uncertainty and outward influences. The risk gives a detrimental effect on organizational performances [3]. The supply chains of Ford and Toyota were severely affected by it after the terrorist attacks of September 11, 2001 [4]. A factory that manufactures around 25% of total global output of HDD was stopped because the strongest flooding the first in fifty years occurred in Thailand and then the computer industry and the semiconductor industry were taken a hard knock because shipments of HDD declined over the number of 125 million products [5]. Thus, the network that enterprises think always normal is exposed to great danger which is destroyed and disrupted at any time.

The destruction of a supply chain in Figure 1 has been studied from a topological perspective to evaluate which is the most effective network. The effectiveness of a supply chain was examined in terms of its robustness, responsiveness, flexibility, and adaptivity when its nodes (tiers) were destructed [1] [6]. The disruption of a supply chain, on the other hand, has been studied from a resilience perspective as its inventory and manufacturing capacity can function as a buffer [7]. In reality, the two factors should be simultaneously considered because the destruction and the disruption of a supply chain multiply occur in a network. But, heretofore a study has not been carried out to concurrently consider a risk of destruction and disruption. That is, it is necessary to evaluate and control the effect of a network which reflects product and information flow of a supply chain and considers the real condition of a supply chain which is becoming affected by surrounding circumstances because a supply chain is not an ideal network.

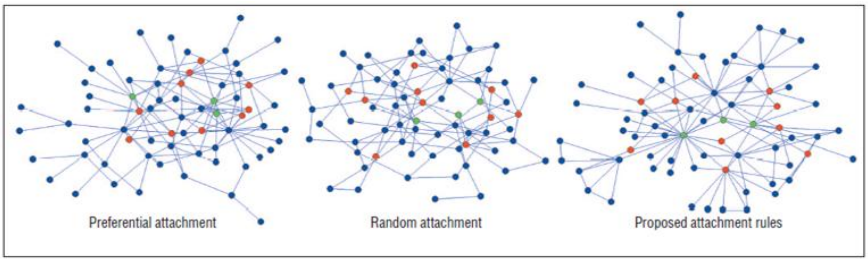

Figure 1. Various networks in topological view [6]

This paper, therefore, considers a supply uncertainty and a demand uncertainty of a supply chain and proposes a method to evaluate and control the supply chain which has a risk of destruction and disruption in view of agent-based simulation (ABS) and System Dynamics (SD).

In Section 1, this paper explained the concept of disaster, risk, destruction, and disruption. Also this study described the reason why we should consider a risk of destruction and disruption in an enterprise network. Agent-based modeling and System Dynamics will be explained in Section 2. In Section 3, this study will explain a supply chain model using agent-based modeling and System Dynamics and make 3 test models. In Section 4, this paper will evaluate the test models and analyze the results and also propose a method to control a risk of destruction and disruption of a supply chain enterprise network. Finally, in Section 5, this paper will explain conclusions and bring out future works.

2 Modeling Concept

2.1 Agent-based Modeling

The efficiency optimization of a supply chain which is connected to business is associated with a product and a part coming from companies dispersed in all over the world. Also, the importance and the difficulty of a supply chain are increasing more and more because a manager tries to increase availability of a product while decreasing inventory. The agent-based modeling of a supply chain, therefore, is a good method to study the process of order fulfillment and to evaluate the efficiency of a business strategy, and the usability of agent-based model (ABM) is increasing to achieve the objectives [8].

Agent-based model coincides with the evaluation of a supply chain because it is possible to make an agent model with rules which are possessed by related companies. An agent, also, easily makes a model not only a product process from an organization to an organization but also the information flow of order quantity and lead time.

Moyaux et al. [9] explained that an agent is hardware or a software-based computer system which has the characteristics of autonomy, social ability, reactivity, and pro-activeness. Wooldridge [10] explained that an agent is a computer system which can do independent and sustainable activities and a multi-agent system (MAS) is composed of many agents which can exchange a message and interact with each other. An agent, also, means that an interactive entity which influences on circumstances in a complex and quicksilver condition through a sensor in order to achieve goals using an actuator.

Wikipedia [11] explained that “An agent-based model is a class of computational models for simulating the actions and interactions of autonomous agents (an individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole. It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming.” Macal & North [12] explained that “Agent-based modelling and simulation (ABMS) is a relatively new approach to modelling systems composed of autonomous, interacting agents. Agent-based modelling is a way to model the dynamics of complex systems and complex adaptive systems.” An agent has simple rules and a behavior which is often explained by interaction with other agents. And the agents affect each other by their behaviors.

The activity principal of used agent is illustrated in Figure 2 [12]. An agent model is associated with an agent attribute and an agent method which operates an agent. An agent attribute can be static, not changeable during the simulation, or dynamic, changeable as the simulation progresses. For example, a static attribute is the name of an agent and a dynamic attribute is a memory which stores the result of past interactions. An agent method includes a behavior such as a rule or more abstract representations which link the situation and the activity of an agent. For example, an agent uses a method to identify a neighbor.

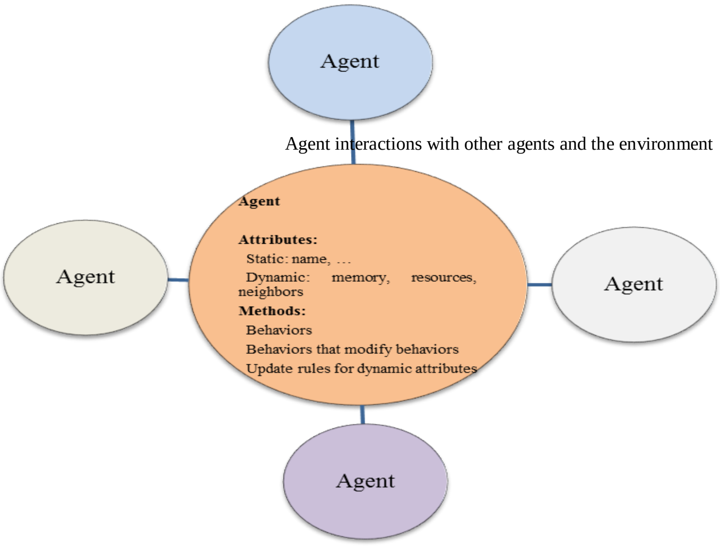

Figure 2. A typical agent

2.2 System Dynamics Modeling

System Dynamics is a method to establish complex interrelation among various variables through dynamic simulation about three analysis issues (feedback relationship, time-delay relationship, and non-linearity relationship). The basic concept of the method started from Gordon Brown's the study of feedback control in the 1950s [13]. Forrester of same university expanded it into business, economy, and social science areas [14] and the method has application to SCM and the others [15].

Sterman [16] explained that "System Dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System Dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations. Together, these tools allow us to create management flight simulators-microworlds where space and time can be compressed and slowed so we can experience the long-term side effects of decisions, speed learning, develop our understanding of complex systems, and design structures and strategies for greater success."

Homer et al. [17] described that "The system dynamics approach involves the development of computer simulation models that portray processes of accumulation and feedback and that may be tested systematically to find effective policies for overcoming policy resistance." Borshchev & Filippov [18] explained that System Dynamics is focusing on high abstraction, less details, macro level, and strategic level and the range of System Dynamics applications includes social, urban, and ecological types of systems.

This study uses AnyLogic [19] to connect an agent-based model and System Dynamics becasue AnyLogic is the only tool that allows you to combine System Dynamics model components with components developed using agent based or discrete event methods. In System Dynamics the real-world processes are represented in terms of stocks (e.g. of material, knowledge, people, money), flows between these stocks, and information that determines the values of the flows. System Dynamics abstracts from an event and entities and takes an aggregate view concentrating on policies.

Because a supply chain network includes always dynmaic property and uncertainty, the basic process of the network which mamufactures a product and gives the product to customers can be modeled by System Dynamics (Figure 3). In a supply chain if a manufactured product and delivery route per Manufacturer are different, a separate and sub supply chain is made by a product group. That is, dynamic properties and uncertainties which are reflected in the manufacturing process of a product group are modeled by System Dynamics per a product group.

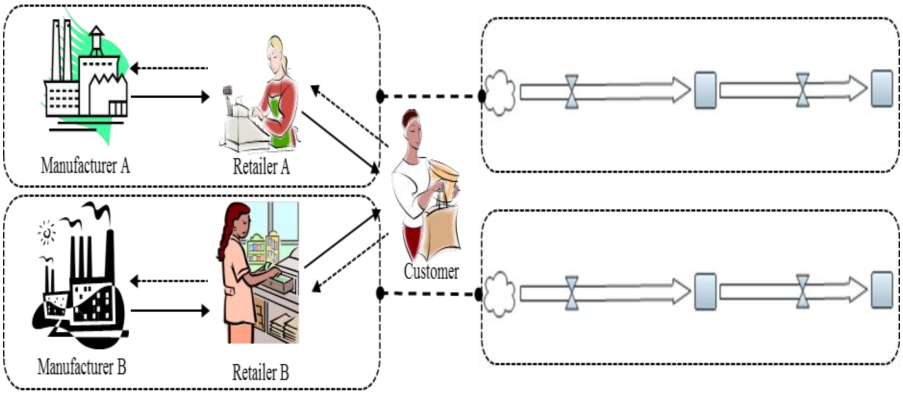

Figure 3. The modeling of an supply chain network using System Dynamics

3 Agent-based Supply Chain Model

In a supply chain model, a network environment is expressed through links and the tiers (or units) of a supply chain such as Factory, Wholesaler, Distributor, Customer, and etc. are expressed by agents. These tiers have their own policies to satisfy inventory control and order fulfillment. Manufacturing capacity and schedule, and etc. are expressed as properties and they are interacting through agent simulation. That is, a supply chain manager agonizes and finds a solution through agent simulation modeling about "How we can obtain the best output at minimal cost?"

This study uses an AnyLogic model [19] [20] as a basic model and also extends the model to test a risk of destruction and disruption (Figure 4).

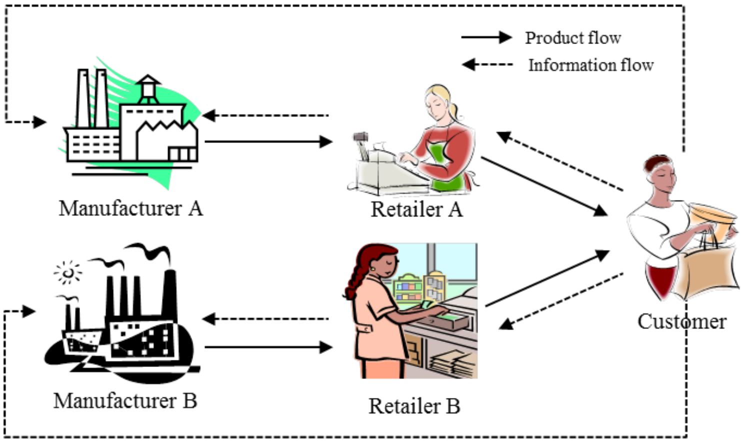

Figure 4. A normal supply chain

This model supposes that Manufacturer A makes a product, A and Manufacturer B makes a product, B and Manufacturer A and B send products to Retailer A and B with a distribution time, 2 days, each. Manufacturer A and B make manufacturing production using order information which is collected from customers and the tentative information of customers, not order information requested from Retailer A and B. It is supposed that 1,000 customers buy a product, A or B through their preferences during a given time, Uniform (17, 23) days and there is no choice between a product (A and B). If a customer does not buy a product he/she wants, he/she will be able to wait for a period of time, 2 days, and then he/she can buy a product whatever. Customers are sensitive to advertising and to word of mouth. Advertising generates the demand for a product among the potential customers and advertising effectiveness, 0.011, is the percent of potential customers that become ready to buy a product (A or B) during a day. Customers can contact each other and a customer contacts on average a contact rate, 5, other people per day. During those contacts the customers of products may influence potential customers. If a customer of a product (for example, A) contacts a potential customer, the latter will want to buy a product (A) with probability adoption fraction, 0.015, same for B.

A supply chain network (for example, Manufacturer A→ Retailer A→ Customer) and a supply chain network (for example, Manufacturer B→ Retailer B→ Customer) are explained as separate networks which do not affect each other. In a normal supply chain environment, therefore, the networks do not affect each other but only they are affected by a customer's behaviors. A real supply chain network does not act ideally and has many problems. This study, so, analyzes these problems in view of destruction and disruption of a supply chain network and then proposes an alternative.

Figure 5 explains that a supply chain network may have a risk of destruction and disruption because the network is weak and has uncertainty. For example, if Manufacturer A was totally destroyed and Retailer A does not know the information that Manufacturer A was destroyed, Retailer A will request continuously order to Manufacturer A. If Manufacturer B was temporarily suspended and Retailer B does not know the information that Manufacturer B was suspended, Retailer B will request continuously order to Manufacturer B. As time goes on the temporary suspension of Manufacturer B will be resolved but the order of Retailer A will not get solved. As time goes on Retailer A will keep up with the problem of Manufacturer A and then Retailer A will change its order to Manufacturer B from Manufacturer A because Manufacturer A and B belong to the same supply chain network.

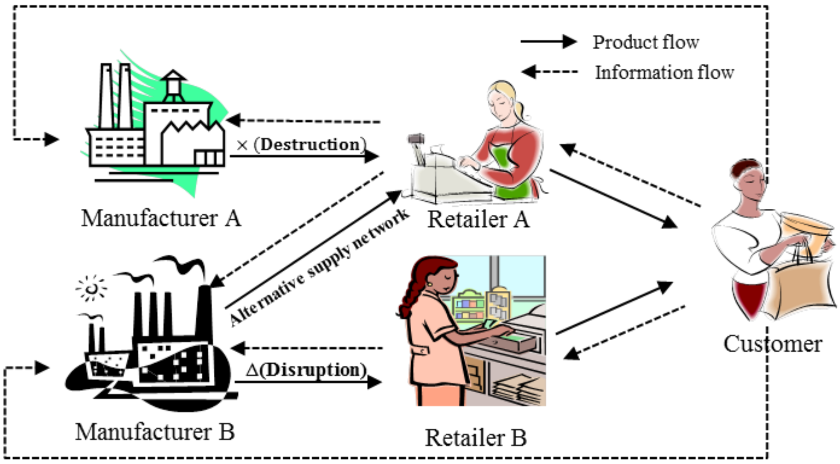

Figure 5. An abnormal supply chain with a risk of destruction and disruption

Figure 6 proposes 3 test models (Case 1 to Case 3) in more detail about problems which are occurred in a supply chain network. Case 1 explains the destruction of Manufacturer A and Case 2 shows the disruption of Manufacturer A. Case 3 describes Retailer A changes its order to Manufacturer B from Manufacturer A because Manufacturer A was totally destroyed.

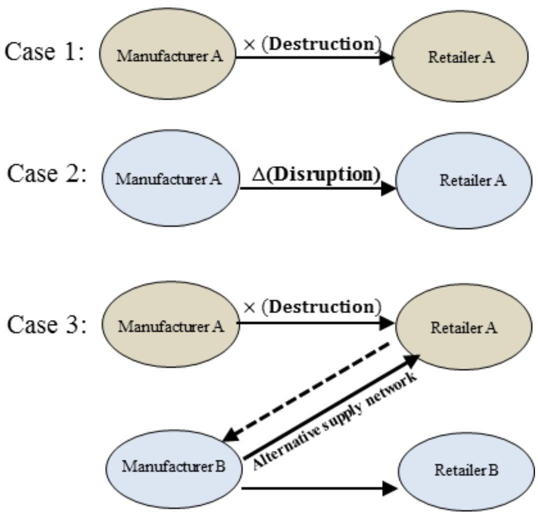

Figure 6. 3 test models with a risk of destruction and disruption

The area of a business application uses System Dynamics, process-centric (or discrete event), and agent modeling method to develop a model. System Dynamics and process-centric make a model of things in view of top-down which is a system level and agent modeling makes a model of things in view of bottom-up. That is, agent modeling is focusing on behaviors of each object. This paper, therefore, uses simultaneously agent modeling and System Dynamics to consider the dynamic properties of a system.

Figure 7 and 8 explain the supply chain of production and delivery of product A and B using System Dynamics. Manufacturer A and B manufacture required manufacturing quantities which are gathered from customers' order information per fixed event time. If the production process is completed, the product sends to Retailer A and B during delivery time.

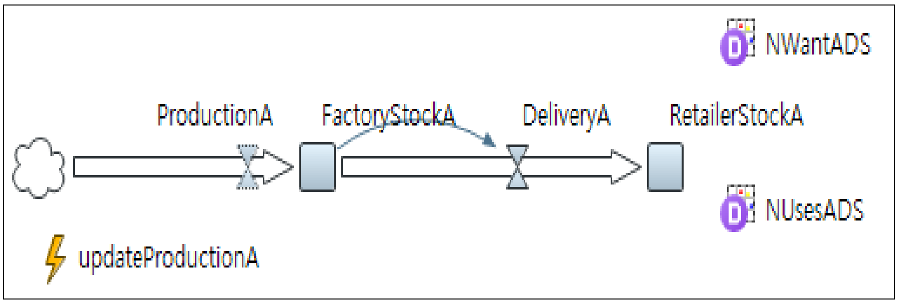

Figure 7. The System Dynamics modeling of product A

Fig. 7 and 8 describe the modeling result which is made by Stock, Flow, and Link of System Dynamics. The System Dynamics modeling of product A is modeled in Figure 7 and the System Dynamics modeling of product B is modeled in Figure 8.

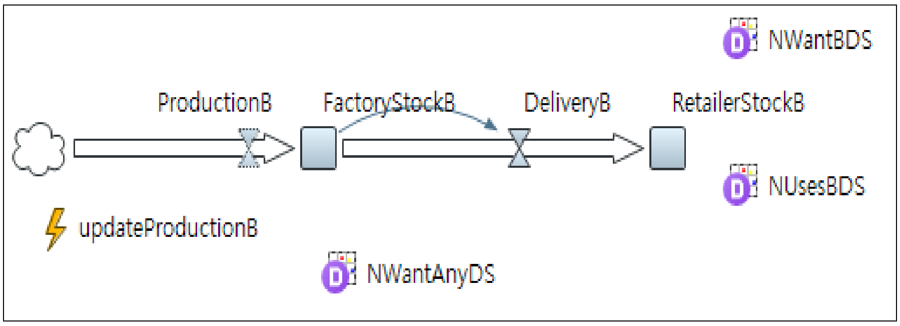

Figure 8. The System Dynamics modeling of product B

A customer should select a product wanted between product A and B, wait the given time if there is no a product to buy it, and buy another product if there is no a product wanted in the given waiting time. We call these dynamic properties and make a model using statechart of AnyLogic [19]. Therefore, the model of a customer's behaviors which reflect a customer's dynamic properties is expressed in Figure 9.

AnyLogic [19] describes that "statechart is the most advanced construct to describe event- and time-driven behavior. For some objects, this event- and time-ordering of operations is so pervasive that you can best characterize the behavior of such objects in terms of a state transition diagram – a statechart. Statechart has states and transitions. Transitions may be triggered by user-defined conditions (timeouts or rates, messages received by the statechart, and Boolean conditions). Transition execution may lead to a state change where a new set of transitions becomes active. States in the statechart may be hierarchical, i.e. contain other states and transitions. Statechart is used to show the state space of a given algorithm, the events that cause a transition from one state to another, and the actions that result from state change."

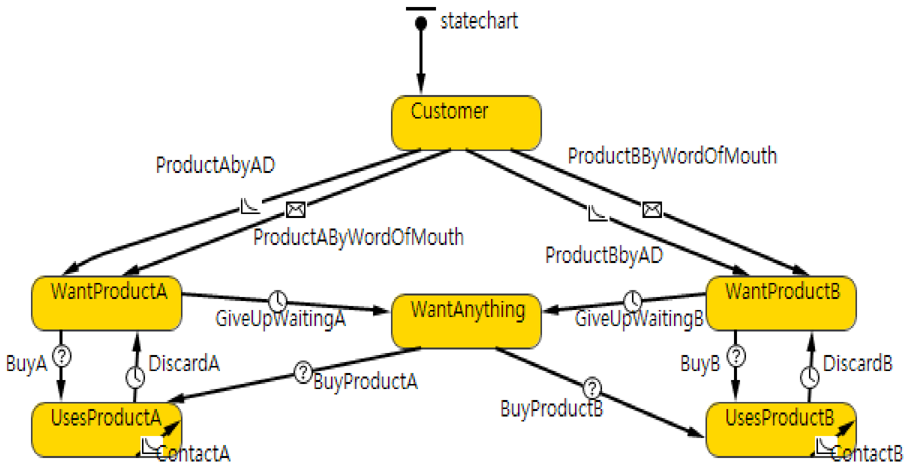

Figure 9. The model of Consumer agent in statechart

Figure 9 shows the modeling of statechart about a customer's properties. A customer selects product A or B according to his/her preference and if the available period of the product is expired he/she changes the product to new product (same type). If the same product is not available he/she should wait the given time and then he/she will use it if the same product is available. He/she should use any product if he/she can't use the same product after the given waiting time. This process is modeled by statechart in hierarchical steps.

Also, Manufacturer A and B should not allow out of stock a customer wants if possible. Manufacturer A and B, therefore, should calculate items a customer wants in terms of time frame using event-driven method and then manufacture it.

4 Model Evaluation and Result Analysis

In an agent-based supply chain model of Section 3, this paper proposed 3 test models (Case 1~ Case 3) to evaluate the effect of a risk of destruction and disruption of an enterprise network. In this Section, this paper proposes a method to analyze the effect on the given test models influence to the entire network and to control the network.

If there is no a risk of destruction and disruption it is a normal supply chain and then the demand and supply of product A and B is 50:50 (Figure 10). In Figure 10, the horizontal axis explains simulation time and the vertical axis describes production quantity of product A and B.

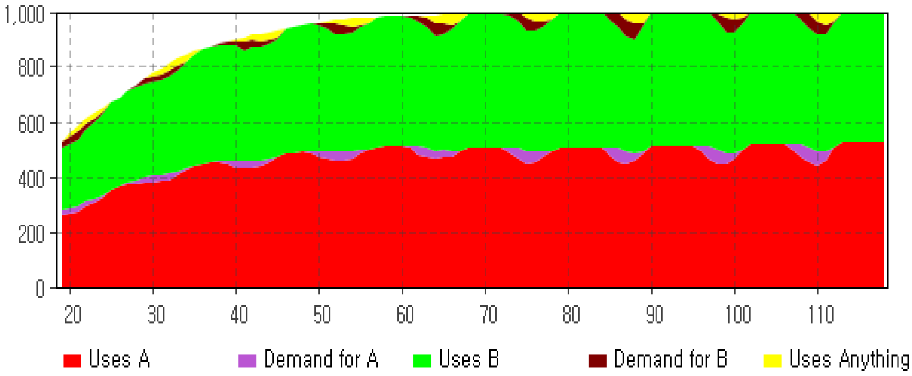

Figure 10. Demand and supply of normal supply chain

This explains that it is well-balanced between a demand and a supply through the quantity changed of products. And it means that the entire supply chain becomes complementary relation and works normally.

The effect caused by a risk of destruction and disruption of a supply chain is analyzed by the results of Case 1 ~ 3.

The result of Case 1 explains that Manufacturer A cannot give Retailer A the volume of orders requested because Manufacturer A was destroyed (Figure 11). That is, Manufacturer A cannot respond appropriately on normal demands consistently requested by Retailer A because it was destroyed. Manufacturer A meets the demands (Uses A(red color) of Figure 11) of Retailer A using holding inventories. If all inventories are exhausted the supply chain network from Manufacturer A to Retailer A is destroyed and dissipated. Retailer A wants to buy product A but Retailer A cannot buy product A (Uses Anyting(yellow color) of Figure 11) from Manufacturer A because Manufacturer A was destroyed and the inventory of Manufacturer A was exhausted. Finally these facts will affect to the whole suppy chain network. On the other hand, because Manufacturer B which belongs to the same supply chain does not know the information that Manufacturer A was destroyed, Manufacturer B faithfully responds to only the order information (Uses B (yellow-green color) of Figure 11) of Retailer B and mistakes that the entire supply chain carries out a stable business. That is, Manufacturer B cannot know that the whole supply chain confronts a danger.

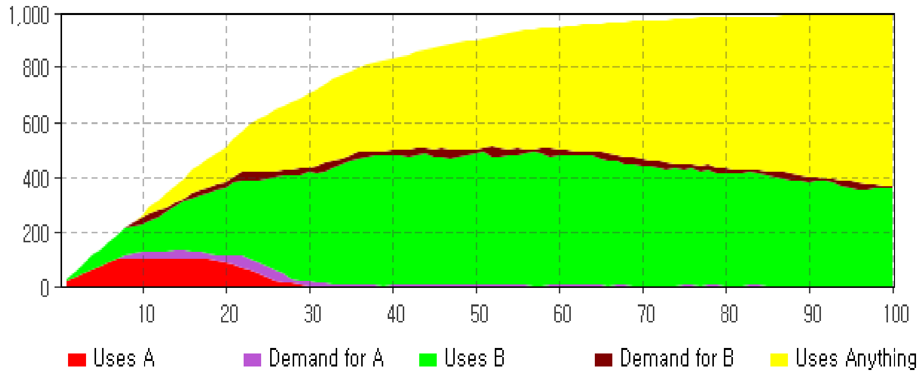

Figure 11. The result of Case 1

Figure 12 shows the result that Manufacturer A is disrupted for a certain period of time. It is supposed that Manufacturer A is disrupted as soon as simulation begins and Manufacturer A will be restored 50 days later. If disruption is occurred Manufacturer A(Uses A(red color) of Figure 12) gives the holding invetory to Retailer A and then tries to endure the hard time but the inventory of Manufacturer is exhausted shortly (30 days later). Retailer A wants to buy product A (Uses Anything(yellow color) of Figure 12) from Manufacuter A but Retailer A should not buy products from Manufacturer A. The disruption of Manufacturer A is solved after 50 days pass and then Manufacturer A makes product A to satisfy the demand of Retailer A. Finally the supply chain will become stable as time passes.

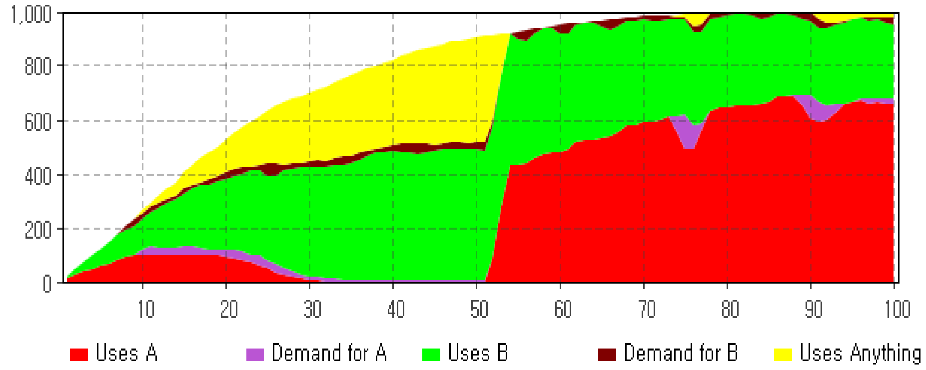

Figure 12. The result of Case 2

Figure 13 shows the result of Case 3 that if Manufacturer A was destroyed, Retailer A requests order quantity to Manufacturer B to secure same order quantity. Retailer A provides same demand information to Manufacturer B and then Manufacturer B tries to procure necessary order quantity. If Manufacturer A is disrupted by some problems the company tries to meet the demand for customers using available holding stock (Uses A(red color) of Figure 13). But the holding stock is exhausted and the enterprise cannot respond to customers' requests anymore. So, Retailer A changes order route from Manufacturer A to Manufacturer B to satisfy customers. Manufacturer B increases output to meet the orders of Retailer A and B (Uses B(yellow-green color) of Figure 13).

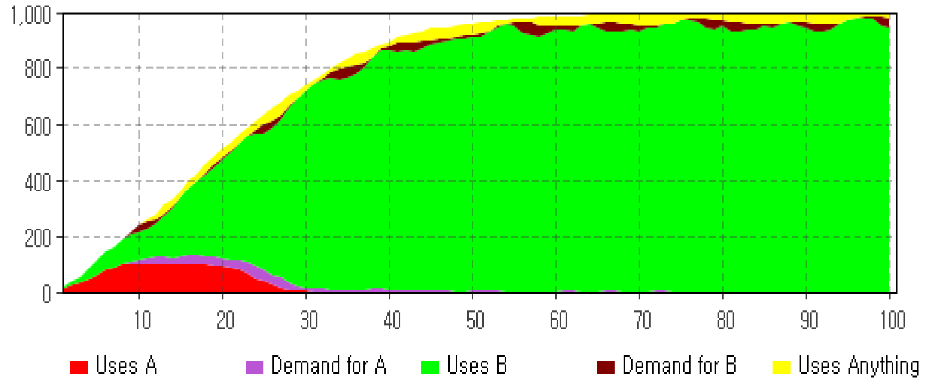

Figure 13. The result of Case 3

There is no role of Manufacturer A in Figure 13. Even if Manufacturer B takes over the role of Manufacturer A and then the supply chain looks like a safety state, the enterprise network will be failed soon because Manufacturer A cannot join the same supply chain.

A concomitant feature from the experimental results is that a risk of destruction and disruption of a supply chain gives a direct influence to the entire supply chain. It is necessary that the enterprises of a supply chain network should coordinate each other because the risk is a serious factor to the companies that work normally business.

5 Conclusions and Future Works

This paper proposed a method to analyze a supply chain network with a risk of destruction and disruption using an agent-based modeling and System Dynamics and to control it. Manufacturer, Retailer, and Customer were modeled as agents to apply agent-based simulation. System Dynamics was used to describe tiers' activities in a supply chain network model. Customer, also, was modeled by statechart of AnyLoic because it should consider various conditions and situations about product A and B which can be bought. There were many tools to make a simulation model, but this study used AnyLogic because the tool is the only software to simultaneously connect an agent-based model and System Dynamics.

This study made the test models, Case 1~ Case 3 and analyzed the results to grasp the effect that a risk of destruction and disruption of a supply chain gives to the entire enterprises' network.

Case 1 tested a scenario that Manufacturer A was destroyed and did not act a member of the same supply chain network. It was supposed that Retailer A ordered continuously because Retailer A did not know Manufacturer A was destroyed. Case 2 experimented with a scenario that Manufacturer A was disrupted for a certain period of time and then it recovered and operated to satisfy the order of Retailer A. It was supposed that Manufacturer A was disrupted from the beginning of simulation and it recovered 50 days later. Case 3 tested a scenario that Retailer A knew Manufacturer A was destroyed and then Retailer A ordered to Manufacturer B. It was supposed that Manufacturer A was not included in the same supply chain network because it was destroyed and Manufacturer B met the order of Retailer A and B at the same time. It, also, was supposed that Manufacturer A had initial inventory to protect unusual conditions but it did not maintain heavy stocks because there was many inventory costs to hold inventory.

From the result analysis, in the same supply chain network, if a company has a problem the problem affects other many enterprises which are not directly associated with the company. Even if information sharing was possible among the companies which are included in the same supply chain network, this paper identified that other companies do not guarantee a company which has a risk. Also, this study proposed that all companies included in the same supply chain network should build a coordination scheme each other to solve the problems.

In this paper, also, it was supposed that customers who do business with a supply chain should wait during the supply chain will recover if a problem was occurred in the supply chain. Or it was supposed that customers purchased an alternative product of an original product from other companies in the same supply chain network. But, in a practical supply chain network customers will not wait time if their supply chain has broken down and also they take no interest in where a desired product is produced. It, therefore, should be known that the threat of a supply chain network caused by a risk of destruction and disruption gives much more fatal results than the test results of this paper. The enterprises which are located in the same supply chain network may conclude that their network is safe because their network works normally in the short term even if other companies have a problem. But, it should be known that other companies' problems will give a negative effect on their supply chain network as time passed. That is, a company may rapidly increase product volume by request of enterprises which are located in the same supply chain and excessively maintain stock to handle conditions. These situations cause the increasing of defective goods and inventory cost, and etc. Finally the supply chain network will be a slippery situation.

This study proposed that all enterprises should collaborate with each other and control effectively the risk when a risk of destruction and disruption is occurred. A viable control strategy is warranted, however, to solve a risk of destruction and disruption of an enterprise network and to further improve it if needed.

6 ACKNOWLEDGEMENTS

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