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공급사슬시스템을 위한 유연성의 측정과 관리
Measurement and management of flexibility for the supply chain system

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Abstract

The object of this study is the development of a measuring framework for supply chain flexibility. Prior to treat supply chain flexibility, time flexibility, quantity flexibility, and cash-flow flexibility for each company are newly suggested. Especially, all developed measures can deal with the monetary point of view through various cost functions. Then weights of time flexibility, quantity flexibility, cash-flow flexibility are determined to find the effect of the level of flexibility in the supply chain. This is based on the relationship between the ratio of profit to revenue and value of three developed flexibility measures. To find the level of weight for each flexibility measure, neural network theory is used. Then the forecasting of the ratio of profit to revenue for all companies in the next period can be available. Therefore, all companies in the supply chain can control their operating processes to improve flexibility.

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1. Introduction

Since there is internal and external uncertainty which is oriented from the globalization, changing customers' needs, and so on, it is not easy to manage the supply chain effectively. For this reason, it is important to make the plan considering uncertainty in the supply chain. This problem can be explained as the concept of flexibility. Flexibility is defined as the ability of a system or facility to adjust to changes in its internal or external environment (Das, 1996). Since flexibility is suitable to express the status of any systems which is dependent on uncertain events, this is used to analyze the performance of manufacturing systems, transportation systems, and so on. Moreover, the supply chain is influenced by many uncertain factors. Therefore, supply chain flexibility is considered as an important concept to illustrate the status of the supply chain, and some measures had been developed.

Voudouris (1996) suggested a mathematical programming approach for supply chain planning to maximize flexibility in fine chemical industries. Flexibility is represented by the capacity slacks of operational resources. Beamon (1998) divided supply chain performance measures into a qualitative and quantitative performance measures. In this classification, flexibility belongs to a qualitative performance measures. Das and Abdel-Malek (2003) defined supply chain flexibility as the robustness of the buyer-supplier relationship under changing supply conditions, and developed a quantitative measure for supply chain flexibility. Duclos et al.(2003) represented the concept and six components of supply chain flexibility, which is made up of operations system flexibility, market flexibility, logistics flexibility, supply flexibility, organizational flexibility, and information systems flexibility. Garavelli (2003) suggested the three supply chain structures to represent the level of flexibility. These structures are classified as no flexibility, limited flexibility, and total flexibility according to the number of available products, suppliers, and markets. Through simulation experiments, the supply chain configuration with limited flexibility of either suppliers or assemblers outperforms the other configurations. Supply-Chain Council (2003) released the Supply-Chain Operations Reference-model (SCOR). In the SCOR model, supply chain flexibility is defined as the agility of a supply chain in responding to marketplace changes to gain or maintain competitive advantages, and many related metrics are suggested.

In many previous studies, supply chain flexibility is regarded to be one of the most important concepts to improve the supply chain. But it has exposed many problems. First, flexibility in most studies was dealt with conceptually. Therefore, it is too hard to apply to practical supply chain planning and execution. Although some quantitative measures for supply chain flexibility were developed in previous studies, there is a limit to express the level of supply chain flexibility as time goes on. Since some measures are unilaterally focused on a special feature of flexibility, those can not represent flexibility for the whole supply chain. Moreover, each measure has its own unit. This makes the analysis of supply chain flexibility more difficult. Second, a few developed measures can find the level of flexibility for only one company. Then, it is not enough to show the level of flexibility for the whole supply chain. Third, some measures were developed as the weighted average which is combined with several unilateral measures to represent supply chain flexibility. However, there is no definiteness to decide the various weights of some unilateral measures. Fourth, developed measures cannot deal with the changing of environments as time goes on. In most studies, flexibility is recognized as the ratio of satisfied orders to total orders. If the production cost or delivery cost are fluctuated as time goes on, it is necessary to consider the monetary point of view to develop more realistic flexibility measures. Fifth, most measures can be considered to be after-the-fact measures. Supply chain planning and execution based on after-the-fact measures is not very effective (Lapide, 1998). Therefore, the procedure to forecast future flexibility is needed to effectively respond to future uncertainty. Finally, the monetary point of view for the supply chain was ignored.

In this study, a new measuring framework and its related measures to treat supply chain flexibility are suggested. Our measuring framework is based on time flexibility, quantity flexibility and cash-flow flexibility, since many of the uncertainties which existed in the supply chain can be realized and analyzed through the change of the quantity of products, the number of satisfied orders until the due-date, and the amount of money collected. These measures can deal with the monetary point of view through various cost functions. Moreover, supply chain flexibility is realized as the profit. However, the level of profit of each company is differently represented owing to the characteristics of each company. Therefore, the ratio of profit to revenue in a certain period can be considered as the combination of time flexibility, quantity flexibility and cash-flow flexibility on the supply chain. If the weight can be defined, we will determine the appropriate level of time flexibility, quantity flexibility and cash-flow flexibility through the control of operating processes to increase the ratio of profit to revenue for companies in the supply chain. To find the value of weight, neural network theory is suggested. With neural network theory, our measuring framework can find the appropriate value of weight, respond as time goes on, and remove the disadvantages of after-the-fact measures. Therefore, it is easy to apply this framework to practical supply chain planning and execution.

The paper is organized as follows. In the next section uncertainties which have an effect on flexibility are released, and measures for time flexibility, quantity flexibility, and cash-flow flexibility are suggested in section 3. In section 4, a new measuring framework for supply chain flexibility with neural network theory is presented. Closing remarks are provided in section 5.

2. The effect of uncertainty on supply chain flexibility

There are three flows which are material flow, information flow, and cash flow in the supply chain. Many companies are trying to effectively manage these flows in the supply chain. Therefore, it is necessary to find various uncertainties which have an effect on supply chain flexibility in these flows. In material flow, the object is to produce and deliver a product with the right state. To increase flexibility for a company, the following uncertainties have to be managed effectively. In the upstream of the supply chain, procurement of high quality raw materials or parts from multiple suppliers in a short lead time is helpful to increase flexibility. A company must produce high quality products using enough production capacity, and deliver products by their due-dates. Sometimes, a company has to work with various subcontractors. This can be good to promote the companies' flexibility. In information flow, it is essential to be equipped with effective information systems. Since the systems make the supply chain visible, flexible supply chain planning and execution are available. In cash flow, fast collection of money gives the chance to respond to the changes in the supply chain. Therefore, fast collection of money is important to improve flexibility. Although these characteristics are just for a certain company, most companies share these characteristics with many companies in the supply chain.

However, it is difficult to consider all the uncertainties, since there is no definiteness to represent supply chain flexibility. But, all uncertainties are realized as the time to supply products, the quantity delivered to customers, and the amount of money received from buyer. Moreover, all activities by companies are for the improvement of the ratio of profit to revenue of a company and the supply chain. If the relation of the three flexibility measures and the ratio of profit to revenue can be found, a new measuring framework for supply chain flexibility can be developed. Therefore, time flexibility, quantity flexibility, and cash-flow flexibility have to be developed in advance to treat the measuring framework for supply chain flexibility.

3. Components of supply chain flexibility

3.1 Time flexibility

For a company, the change in the due date makes manufactures confused. If a buyer advances the due date, a manufacturer has to try to satisfy the buyer's demand. Sometimes, this manufacturer needs more expenses to produce, and contract with subcontractors. If a buyer postpones the due date, a manufacturer has to consider costs like additional inventory costs or re-scheduling cost. If the level of change is more than that of the maximum time to supply the order economically, a manufacturer can not satisfy the demands. Then, time flexibility for a company in the period t, TF_t, can be shown in equation (1).

Indices

i	index for orders
j	index for products
t	index for unit periods
n	number of orders
m	number of products

Notations

$tf_{tij}(\bullet)$	cost function to fill the i th order for product j in the period t
pts_{tij}	planned time period to fill the i th order for product j in the period t
rts_{tij}	realized time period to fill the i th order for product j in the period t
$Maxts_{tij}$	maximum available time period to fill the i th order for product j in the period t economically
p_{tij}	$\begin{cases} 1 & \text{, when the } i \text{ th order for product } j \text{ in the period } t \text{ is treated} \\ 0 & \text{, otherwise} \end{cases}$

$$TF_t = \frac{\sum_i^n \sum_j^m \left\{ Min\left(1, 1 - \frac{tf_{tij}(rts_{tij}) - tf_{tij}(pts_{tij})}{tf_{tij}(Maxts_{tij}) - tf_{tij}(pts_{tij})}\right) \cdot p_{tij} \right\}}{n} \quad (1)$$

where

$$\text{let } Min\left(1, 1 - \frac{tf_{tij}(rts_{tij}) - tf_{tij}(pts_{tij})}{tf_{tij}(Maxts_{tij}) - tf_{tij}(pts_{tij})}\right) \cdot p_{tij} = 0 \quad \text{, if } Maxts_{tij} \le pts_{tij}$$

The maximum value of TF_t is equal to 1, and the minimum value is 0. If the small difference between realized time period and planned time period is recorded, the higher value of TF_t will be returned, and if not, the value of TF_t will be decreased. The maximum value 1 means that a company has complete ability to adjust to the change of the due date for orders. But, the minimum value 0 represents no ability to control for the change of the due date.

3.2 Quantity flexibility

If the quantity of products is changed, a company spends more money to respond to demands. For increased quantity, it is necessary to magnify production or to find various subcontractors. On the other hand, inventory cost will be increased for decreased quantity. But, the cost for emergency production through subcontractors is more than that for normal production. If the changed quantity is more than the maximum available quantity to make a product economically, a company will cancel this order. Moreover, if backorder occurs, flexibility will be decreased. Then, quantity flexibility for a company in the period t, QF_t, can be shown in equation (2).

Indices

i index for orders

j index for products

t index for unit periods

n number of orders

m number of products

Notations

$mf_{tij}(\bullet)$ cost function to make the i th order for product j in the period t

$sf_{tij}(\bullet)$ cost function to make the i th order for product j by the subcontractor in the period t

$bf_{tij}(\bullet)$ cost function for backorder of the i th order for product j in the period t

pq_{tij} planned quantity to make the i th order for product j in the period t

pqs_{tij} planned quantity to make the i th order for product j by the subcontractor in the period t

rq_{tij} realized quantity to make the i th order for product j in the period t

rqs_{tij} realized quantity to make the i th order for product j by the subcontractor in the period t

rbq_{tij} realized backorder of the i th order for product j in the period t

$Maxq_{tij}$ maximum available quantity to make the i th order for product j in the period t economically

$Maxqs_{tij}$ maximum available quantity to make the i th order for product j in the period t by the subcontractor economically

$$p_{tij} \begin{cases} 1 & \text{, when the } i \text{ th order for product } j \text{ in the period } t \text{ is treated} \\ 0 & \text{, otherwise} \end{cases}$$

$$QF_t = \frac{\sum_i^n \sum_j^m \left\{ Min\left(1, 1 - \frac{\alpha_{tij}}{\beta_{tij}}\right) \cdot p_{ij} \right\}}{n}$$

where

$$\begin{aligned} \alpha_{tij} &= mf_{tij}(rq_{tij}) + sf_{tij}(rqs_{tij}) \\ &\quad + bf_{tij}(rbq_{tij}) - mf_{tij}(pq_{tij}) - sf_{tij}(pqs_{tij}) \\ \beta_{tij} &= mf_{tij}(Maxq_{tij}) + sf_{tij}(Maxqs_{tij}) \\ &\quad - mf_{tij}(pq_{tij}) - sf_{tij}(pqs_{tij}) \end{aligned} \qquad (2)$$

$$let\ Min\left(1, 1 - \frac{\alpha_{tij}}{\beta_{tij}}\right) \cdot p_{ij} = 0,\ if\ \alpha_{tij} \geq \beta_{tij}$$

The maximum value of QF_t is equal to 1, and the minimum value is 0. If the small difference between realized quantity and planned quantity to make orders is recorded, the higher value of QF_t will be returned, and if not, the value of QF_t will be decreased. The maximum value 1 means that a company has complete ability to deal with the change of quantity to make orders. But, the minimum value 0 represents no ability against the change of quantity.

3.3 Cash-flow flexibility

Cash-flow flexibility means the rapid collection of the amount of money. If a buyer postpones the payment, many companies in the upstream supply chain have the money flow problem. Therefore, it is important to pay and collect the price of products rapidly. Then, cash-flow flexibility for a company in the period t, CF_t, can be shown in equation (3).

Indices

i	index for orders
j	index for products
t	index for unit periods
n	number of orders
m	number of products

Notations

sp_{tij}	selling price for the i th order for product j in the period t
cp_{tij}	amount of money collected from the buyer for the i th order for product j in the period t

$$p_{tij} \quad \begin{cases} 1 & \text{,when the } i \text{ th order for product } j \text{ in the period } t \text{ is treated} \\ 0 & \text{,otherwise} \end{cases}$$

$$CF_t = \frac{\sum_{t}\sum_{i}^{n}\sum_{j}^{m} sp_{tij} \cdot p_{tij}}{\sum_{t}\sum_{i}^{n}\sum_{j}^{m} cp_{tij} \cdot p_{tij}} \qquad (3)$$

The maximum value of CF_t is equal to 1, and the minimum value is 0. If most of total selling price is collected, the value of CF_t is increased. If not, CF_t is decreased. The maximum value 1 means that a company has complete ability to survive financially. But, the minimum value 0 represents problems collecting the selling price.

4. Supply chain flexibility

In the previous section, the components of supply chain flexibility are suggested. Therefore, supply chain flexibility will be described as the combination of these components. But, there is no mathematical procedure which is enough to organize supply chain flexibility using time flexibility, quantity flexibility, and cash-flow flexibility. Many companies want to improve their profit. Then, profit can be considered as the result of all activities to improve flexibility. But profit is not enough to illustrate the result of all activities, since the characteristics of various companies are not considered. Although two different companies obtain the same profit, the ratio of profit to revenue can be different owing to the characteristics of companies. Therefore, the ratio of profit to total revenue for each company is used to define the weight of time flexibility, quantity flexibility, and cash-flow flexibility. To find weights, neural network theory can be used.

An artificial neural network is defined as an information-processing system that has certain performance characteristics in common with biological neural networks(Fausett, 1994). It has the ability to analyze various problems which can not be solved through any mathematical theories.

Due to the usefulness of neural network theory to measure the characteristics for a system, supply chain flexibility will be analyzed using neural network theory. In this study, weight of each flexibility measure is found in the relationship between value of each flexibility measure and a company's ratio of profit to revenue in a certain period. That is, weight represents the contribution of flexibility measures to all companies' ratio of unit period profit to revenue. However, calculated weights are just a real number in neural network theory. Therefore we can see some negative values, but these do not mean the negative effect of a type of flexibility.

Our neural network structure is a single-layer neural network whose input layer is made up of all the values of each flexibility measure, and output layer is made up of all companies' ratio of profit to revenue. If we intend to organize the neural network for the 4 companies, we will have a bias node and 12 input nodes in the input layer and 4 output nodes in the output layer. All 12 input nodes for 4 companies must be connected with all output nodes to represent the effect of flexibility of a company on the other companies in the supply chain. This structure can be represented in Figure 1.

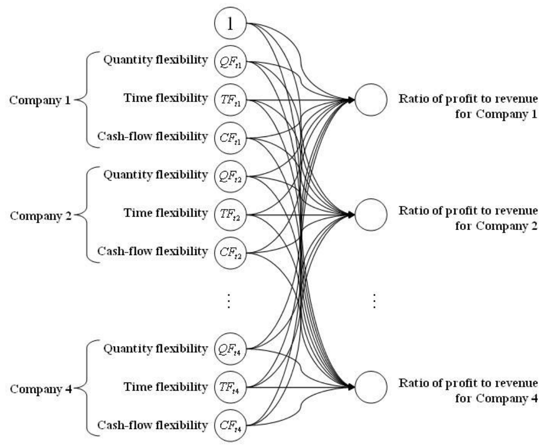

Figure 1. The structure of the neural network for supply chain flexibility

Generally, a multiple-layer neural network is known to be a better structure than a single-layer neural network for effective learning. However, the type of problem does not uniquely determine the choice of architecture (Fausett, 1994). Moreover, the objective of this study is the development of measuring framework for supply chain flexibility and weight can be easily calculated in a single layer structure, we will propose a single layer neural network for the convenience. If it is necessary to learn the complex system, a multiple-layer neural network can be used. Weights are determined by the backpropagation rule.

Therefore, the measuring framework for supply chain flexibility in each period can be represented in the following procedures.

Step 0. Collect data of orders, products, number of orders, number of products, time, quantity, cost functions, amount of money, and so on in the period t.

Step 1. Calculate the value of time flexibility, quantity flexibility, and cash-flow flexibility based on reported data in the period t.

Step 2. Find weights between the value of all flexibility measures and the ratio of profit to revenue of all companies using neural network theory.

Step 3. Forecast the ratio of profit to revenue in the next period $t+1$. If the result is not satisfied, it is necessary to control the operating process to improve the ratio of profit to revenue to be realized in the next period $t+1$.

Through this procedure, we can easily manage the profit of all companies with the control operating processes in the point of view time flexibility, quantity flexibility, and cash-flow flexibility. Moreover, this measuring framework can free us from the limit of previous after-the-fact measures. Therefore, the forecasted ratio of profit to revenue in the next period $t+1$ will be helpful for the effective supply chain planning and execution. Moreover, if a new concept is newly considered to be important, this can easily be added in the input node. Therefore, this measuring framework is very flexible.

5. Conclusion

In this study, the measuring framework to treat supply chain flexibility for companies in the supply chain is suggested. First of all, measures for time flexibility, quantity flexibility, and cash-flow flexibility for a company were developed. However, these measures are unilateral for a company made up of the supply chain. Since there is not any mathematical relationship between each measure and supply chain flexibility, we suggested the measuring framework for supply chain flexibility using neural network theory with the value of flexibility measures and the ratio of profit to revenue for companies. By this framework, each company can forecast the ratio of profit to revenue in the next period easily. Then, each company controls its operating process to improve flexibility.

Although this measuring framework has many advantages, there can be the limitation. Generally, more flexibility does not mean more profit always. That is, more costs can be required to improve flexibility sometimes. In this condition, it will be good to determine an appropriate level of flexibility measures to minimize total cost in the supply chain. Therefore, it is necessary to consider the determination of the appropriate level of flexibility measures.

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