28 SUPPLY CHAIN MANAGEMENT BASED ON MARKET MECHANISM IN VIRTUAL ENTERPRISE

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Supply chain management is not always concerned with the optimal solutions in terms of product distribution. Market mechanism solves product distribution problem by allocating the scheduled resources according to market prices. We formulate supply chain model as a discrete resource allocation problem, and demonstrate the applicability of economic analysis to this framework. The proposed algorithm facilitates sophisticated supply chain management, which conducts a pareto optimal solution in product distribution system.

INTRODUCTION

There is a growing recognition that current manufacturing enterprises must be agile, that is, capable of operating profitably in a competitive environment of continuously changing customer demands. A prominent characteristic that will distinguish successful manufacturing enterprises will therefore be the ability to respond quickly, proactively, and aggressively to unpredictable change. The use of virtual enterprises (VE), groups of distinct organisations, that cooperate to accomplish a common business goal to achieve the goal of agility is becoming increasingly prevalent. This has been made possible, in part, due to the significant advances in communication and information technology in recent years. However, in the management of effective VE, there exists a lack of methods, tools, and environments to support the integration of process models from multiple organisations into shared VE processes.

Supply chain management (SCM) is one of the global concepts to solve that problem and there find several researches in that area (Fisher, 1994). SCM, however, is based on the simple TOC (Theory Of Constraints), and is not always concerned with the optimal solutions in terms of product distribution (Goldratt,

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The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: 10.1007/978-0-387-35577-1_37

L. M. Camarinha-Matos et al. (eds.), *Infrastructures for Virtual Enterprises*

1983). Market mechanism solves the product distribution problem by allocating the scheduled resources according to market prices.

Solving product distribution problem in SCM presents particular challenges attributable to the distributed nature of the computation. Each business unit in SCM represents independent entities with conflicting and competing product requirements and may possess localised information relevant to their interests. To recognise this independence, we treat the business units as agents, ascribing each of them to autonomy to decide how to deploy resources under their control in service of their interests.

In this paper, a distributed product distribution method can be analysed according to how well it exhibits the following properties:-

i) Self-interested agents can make effective decisions with local information without knowing the private information and strategies of other agents.
ii) The method requires minimal communication overhead.
iii) Solutions don't waste resources. If there is some way to make some agents better off without harming others, it should be done. A solution that cannot be improved in this way is called pareto optimal.

Conventional straightforward distributed policies do not possess these properties.

Assuming that a product distribution problem in SCM must be decentralised, markets can provide several advantages as follows:-

i) Markets are naturally distributed and agents make their own decisions about how to bid based on the prices and their own utilities of the goods.
ii) Communication is limited to the exchange of bids and process between agents and the market mechanism.

In this paper we formulate supply chain model as a discrete resource allocation problem, and demonstrate the applicability of economic analysis to this framework by simulation experiments.

PRODUCT DISTRIBUTION PROBLEM IN SCM

Product distribution in SCM is generally proceeded by distributed autonomous dealings amongst agents. Formal model of the product distribution is shown in Figure 1 and we define a general product distribution problem in terms of the following elements:-

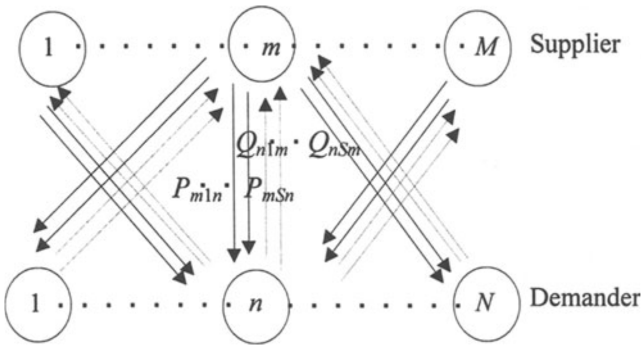


Figure 1 - Product Distribution Basic Model

i) Total number of supply agents, M (Supply agent ID, m)
ii) Total number of demand agents, N(Demand agent ID, n)
iii) Total number of product types, S(Product ID, s)
iv) The amount of supplied products in type s from agent m to agent n, P_{msn}
v) The amount of required products in type s from agent n to agent m, Q_{nsm}

The autonomous dealings amongst the business agents are based on quantity and price of the target products, and the severe conflicts between supplier and demander is always occurs due to the tradeoffs of their utilities. Market mechanism is expected to solve the problems by presenting a pareto optimal solution for all of the agents.

MARKET-ORIENTED PROGRAMMING

Basic Concept

Agent activities in terms of products required and supplied are defined so as to reduce an agent's decision problem to evaluate the tradeoffs of acquiring different products in market-oriented programming. These tradeoffs are represented in terms of market prices, which define common scale of value across the various products. The problem for designers of computational markets is to specify the mechanism by which agent interactions determine prices (Wellman, 1993).

In this paper the framework of general equilibrium theory (Okuno, 1985), which is proposed in micro economics research field, has been adopted. In economics, the concept of a set of interrelated goods in balance is called general equilibrium. The general equilibrium theory guarantees a pareto optimal solution at competitive equilibrium in perfect competitive market. The connection between computation and general equilibrium is not all foreign to economists, who often appeal to the metaphor of market systems computing the activities of the agents involved. Some apply the concept more directly, employing computable general-equilibrium models to analyse the effects of policy options on a given economic system (Shoven, 1992). Obviously SCM model is well-structured for market-oriented programming, and that means the proposed concept takes advantage of the theory, and a pareto optimal solution, which is conducted by micro economics, is attainable in product distribution problem in SCM (Kaihara 1999).

Market-Oriented Programming in SCM Model

In market-oriented programming we take the metaphor of an economy computing a multi agent behaviour literally, and directly implement the distributed computation as a market price system. Figure 2 shows the relationship amongst two types of agents, supplier and demander, and products in market oriented programming paradigm. $Pt(s)$ is the price of product s in time t, f_{tms} is the supply function in supply agent m for product s in time t, and g_{tns} is the demand function in demand agent n for product s in time t.

The algorithm of the proposed market-oriented programming in SCM is shown as follows:

Step1: A demand agent n sends bids to a markets to indicate its willingness to buy the product s according to its current price $Pt(s)$ in time t. The demand agent willingness is defined as a demand function in the bid message. The agent can send bids to the market within the limits of its domestic budget. Each product has its own market, and they construct a competitive market mechanism as a whole.

Step2: A supply agent m sends bids to the market to indicate its willingness to sell the product s according to its current price $Pt(s)$ in time t. The supply agent willingness is defined as a supply function in the bid message. The agent can send bids to the market within the limits of its current inventory level.

Step3: The market in product s sums up demand functions ($\sum_m f_{tms}$) and supply functions ($\sum_n g_{tns}$), then revises balanced price $Pt'(s)$ of product s in time t . All the market must revise their balanced price via the same process.

Step4: Check the balanced prices of all the products and if all the prices are converged, the acquired set of the prices is regarded as equilibrium price, then go to *Step5*. If not, go to *Step1*.

Step5: If dealing time is up, then stop. And if not, t=t+1 and go to *Step1*.

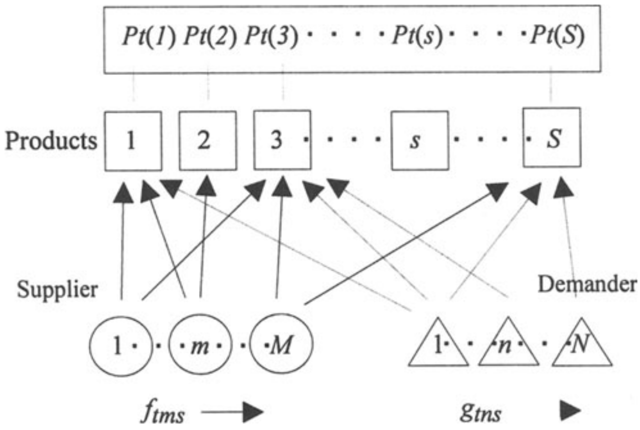


Figure 2 - Market-Oriented Programming

There exist the following subjects to build up an appropriate SCM model with the market-oriented programming concept.

i) Definitions of supply and demand functions in the agents.
ii) Budget constraint in the agents

We try to clarify these subjects in the next section.

AGENT DEFINITIONS

Supply Agent

Suppose supply agent i has production function Hi, which defines manufacturing efficiency from input resources Xi to products Yi. The production function Hi of supply agent i is defined as follows:

$$Yi = Hi(Xi) \qquad (1)$$

where

$$Xi = \{xi1, xi2, \cdots xiS\} \quad (2)$$
$$Yi = \{yi1, yi2, \cdots yiS\} \quad (3)$$

In this paper we adopt a basic Cobb-Douglass function as the production function described in the following equation:

$$y = ax^b \quad \text{(where } 0<a,\ 0<b<1) \quad (4)$$

It is well known that Cobb-Douglass function handles economical scale in market by index constant b, and in case of $0< b <1$ the production function is defined as a convex function, in other words, a diminishing returns function. In case production function is defined as convex type, market prices are established at a predictable level in the general equilibrium theory.

Finally production function h_{is} of agent i for product s is given by

$$y_{is} = h_{is}(x_{is}) = a_{is}x_{is}^{\ b_{is}} \quad (5)$$

Suppose the single unit cost of x_{is} is p_{0is} and the single unit sale of y_{is} is p_{is}, then the profits E_{is} of agent i for product s is defined as (6)

$$\begin{aligned} E_{is} &= p_{is}y_{is} - p_{0_{is}}x_{is} \\ &= p_{is}y_{is} - p_{0_{is}}(y_{is}/a_{is})^{1/b_{is}} \end{aligned} \quad (6)$$

Supply agent utility in the dealing is motivated to earn maximum profit and supply function is conducted from iso-profit curve with maximum return. Finally supply function f_{is} with maximum profit is given as follows:

$$\begin{aligned} {}_{\max}E_{is} &= \partial E_{is}/\partial y_{is} \\ &= p_{is} - (p_{0_{is}}/b_{is})(y_{is}/a_{is})^{(1-b_{is})/\ b_{is}} = 0 \end{aligned}$$

then

$$y_{is} = f_{is}(p_{is}) = a_{is}(b_{is}p_{is}/p_{0_{is}})^{b_{is}/(1-b_{is})} \quad (7)$$

where $0<a_{is}$, $0 < b_{is} < 1$

Demand Agent

Suppose demand agent i has demand function Gi, which defines its demanding amounts Zi of the target products, then we have

$$Zi = Gi(Pi) \quad (8)$$

where

$$Pi = \{pi1, pi2, \cdots piS\} \quad (9)$$
$$Zi = \{zi1, zi2, \cdots ziS\} \quad (10)$$

In this paper we adopt a power function as the demand function described in the following equation:

$$z = cp^{-d} \quad \text{(where } 0<c,\ 0<d) \quad (11)$$

In this function, index constant d indicates "price elasticity", which represents the price effects into demand utility.

$$\begin{aligned} (\text{Price elasticity})is &= (dz_{is}/dp_{is}) * (p_{is}/z_{is}) \\ &= -(dcp_{is}^{\ d-1})(1/cp_{is}^{\ d-1}) = -d \end{aligned} \quad (12)$$

Power function is applied into demand function in this paper, since price elasticity of each product is kept in constant shown in (12). Finally demand function g_{is} of agent i for product s is given by

$$z_{is} = g_{is}(p_{is}) = c_{is} p_{is}^{-d_{is}} \qquad (13)$$

where $0 < c_{is}$, $0 < d_{is}$

Domestic Budget of Agent

In this paper we introduce the idea of budget constraint for demand agents as well as the inventory limitation for supply agents so as to establish more practical SCM model.

Suppose demand agent i has budget constraint Bi, and the relationship between demands and budget constraint are shown in the following equation:

$$B_i \geq \sum_{s=1}^{S} z_{is} p_{is} \qquad (14)$$

Utility Proportional Strategy in Budget Constraint

In market-oriented program each agent is regarded as a price taker. They assume product costs never be affected by their bidding activities during a dealing. Therefore once they detect product prices were altered after their bid, it is necessary for them to modify their bidding functions according to their strategy in order to find a pareto optimal solution shown in the previous section.

We propose utility proportional strategy in demand agents as the modification mechanism. In utility proportional strategy demand agents are assumed to have rigid intention and hold a fixed proportional utilities about all the demanding products during a dealing time period t under their budget constraint. Because index constraint d_{is} in demand functions (13) represents price elasticity, which is unique to product s and should be fixed, a coefficient c_{is} is revised by applying the rule given by (15) in the proposed strategy

$$g_{is}(p_{is}) = \begin{cases} c_{is} p_{is}^{-d_{is}} \left(B_i \geq \sum_{s=1}^{S} z_{0is} p_{0is}\right) \\ c'_{is} p_{is}^{-d_{is}} \left(B_i < \sum_{s=1}^{S} z_{0is} p_{0is}\right) \end{cases} \qquad (15)$$

Since demand and budget relationship is given by equation (16), the newly revised coefficient c'_{is} is given by (17)

$$B_i \left(z_{0is} p_{0is} \Big/ \sum_{s=1}^{S} z_{0is} p_{0is} \right) = c'_{is} p_{0is}^{-d_{is}} p_{0is} \qquad (16)$$

$$c'_{is} = B_i \left(z_{0is} \Big/ \left(\sum_{s=1}^{S} z_{0is} p_{0is} \right) p_{0is}^{-d_{is}} \right) \qquad (17)$$

EXPERIMENTAL RESULTS

Experimental Supply Chain Model

Experimental supply chain model based on computational market is constructed so as to analyse qualitative characteristics of the proposed approach by simulation. The followings are the default experimental parameters in the basic supply chain model.

the number of supply agents	: 3
the number of demand agents	: 3
the number of product types	: 3(A,B,C)
interval time of product supply	: 1(day)
lot size of supplied products from supply agents*	: A:100, B:150, C:200
required product size in demand agents*	: A:100, B:150, C:200
price elasticity of products	: 1.0
Budget size in demand agents	: plenty
value of constants in production function	: a=1, b=1/2
initial value of constants in demand function	: c_0=1, d=1
the number of simulation trails	: 100

*followed by uniform distribution in the interval –20% to +20%

Three types of products {A, B, C} are defined. Product A and C symbolise small lot size product and large lot size product respectively.

Basic Dealing Dynamics

Experimental results on the number of demand(order) / supply(deliver) products at a demand agent are shown in Figure 3.

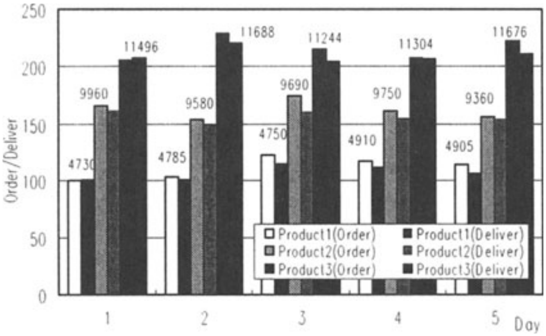


Figure 3 - Products Allocation

Small figures indicate the acquired equilibrium price of each product at daily dealing processes in Figure 3. The daily difference of equilibrium prices, which were acquired as a pareto optimal solution led by general equilibrium theory, are within 3% and it is obvious that dealing process in computational market is settled under budget-constraint free environment.

Supply and Demand Balance

Figure 4 demonstrates the relationship between supply/demand ratio and equilibrium price in product A.

In this figure the horizontal axis is supply/demand ratio, and ratio:1.0 means the number of supplied products is completely equivalent to the number of demanded ones. The vertical axis represents non-dimensional equilibrium price, which is divided by the price acquired at supply/demand ratio=1.0.

As the supply/demand ratio increases, equilibrium price decreases. They are in negative correlation, and the experimental values agree well with the theoretical trends of general equilibrium in micro economics. This result indicates the proposed market-oriented approach successfully constructs a perfect competitive market in product distribution problem in SCM.

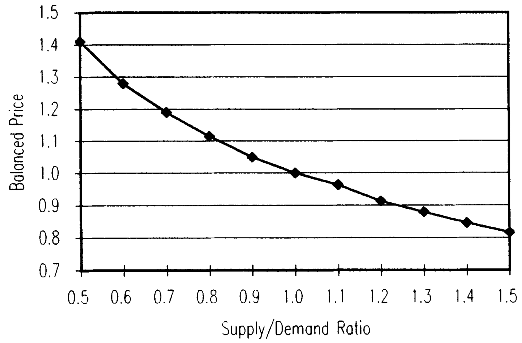


Figure 4 - Supply and demand balance

Budget Constraint and Equilibrium Price

The relationship between budget constraint and acquired equilibrium price is shown in Figure 5. Needless to say, agent strategy under budget constraint is followed by the newly proposed utility proportional strategy, which was described in the previous chapter.

In this figure the horizontal axis represents non-dimensional budget ratio, which is divided by the perfect balanced budget. The vertical axis represents non-dimensional equilibrium price, which is divided by the price acquired at budget ratio=1.0.

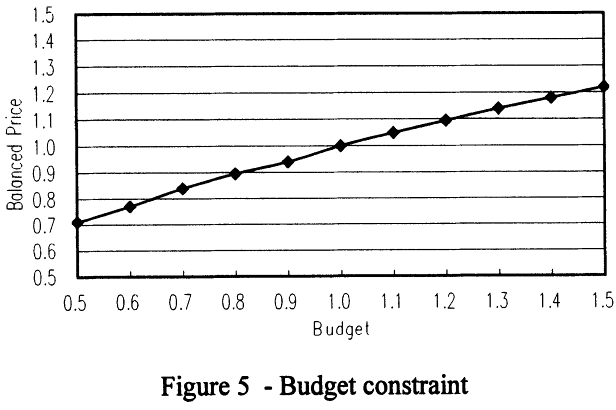
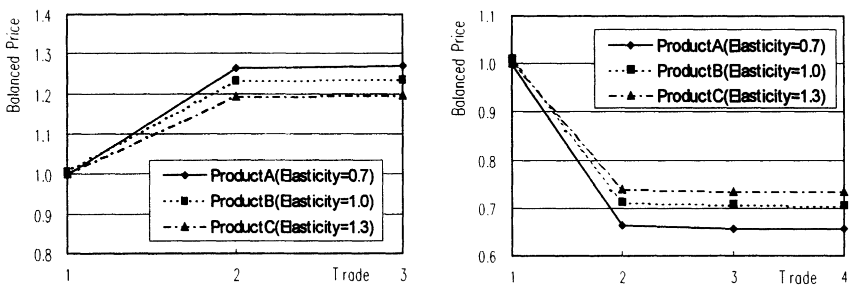


Figure 5 - Budget constraint

They are in positive correlation, and the experimental values agree well with the qualitative trends of general equilibrium theory as well. In general price of goods increases under the condition of plenty of budget in demand agents, because the economy in the competitive market is getting inflated. On the other hand, equilibrium price decreases under deflated economy caused by the shortage of budget in demand agents.

Price Elasticity

The relationship between price elasticity and equilibrium price is shown in Figure 6. In Figure 6 (a) all the demand agents have a plenty of budget (budget scale is 150% compared with the perfect balanced budget), while they face the shortage of budget (budget scale is 50%) in Figure 6 (b).



(a) Budget scale=150% (b) Budget scale=50%

Figure 6 - Price elasticity

In these figures the horizontal axis represents the iteration number in a trade to reach a pareto optimal solution in market oriented programming. It happened to take three and four times to acquire equilibrium prices at a trade in Figure 6 (a) and 6 (b) respectively. The vertical axis represents non-dimensional equilibrium price, which is divided by the initial setting price. Note that the vertical axis does not represent abstract product price.

Price elasticity varies in product type in this experiment so as to investigate the characteristics of proposed approach on price elasticity. Product A and C have lower (=0.7) and higher (=1.3) price elasticity respectively.

As considered in the previous section, plenty of budget in demand agents generally causes higher price of goods shown in Figure 6 (a). The price increase rate of product A with lower price elasticity is greater than those of the other products, because the utility decreasing rate of demand agents on the product A is smaller than the rates on the other products due to lower price elasticity in higher price.

On the other hand, the prices of goods generally decrease in weak economy shown in Figure 6 (b). The price decrease rate of product C with higher price elasticity is smaller than those of the other products, because the utility decreasing rate of demand agents on the product C is smaller than the rates on the other products due to higher price elasticity in lower price.

Discussions

Several characteristics, which are well-known in economics, of the proposed approach were qualitatively analysed by simulation experiments. Simulation results have proved that all the natures of our approach agree perfectly well with the theoretical trends of general equilibrium in micro economics.

Our implementation and experiments successfully demonstrated that the proposed market-oriented approach constructs a perfect competitive market in product distribution problem in SCM. A pareto optimal solution, which is endorsed by general equilibrium theory in competitive market, was acquired in product distribution problem by the metaphor of an economy in multi agent society.

It was quite difficult to implement some distribution algorithm into large-scaled complex SCM in conventional approach. Our approach is completely distributed and a pareto optimal solution is attainable only by defining the supply/demand function into each business units in SCM, because market mechanism equips dealing protocol by nature. Our approach has been proved to be practical and capable of robustness and reliability coping with the several SCM demands.

CONCLUSIONS

SCM is one of the key technologies for effective operation in VE. In this paper we formulated supply chain model as a discrete resource allocation problem, and demonstrated the applicability of economic analysis to the problem. The framework of general equilibrium theory, which guarantees a pareto optimal solution at competitive equilibrium in perfect competitive market, has been adopted.

Simulation results have proved that all the natures of our approach agree perfectly well with the theoretical trends of general equilibrium in micro economics. Our implementation and experiments successfully demonstrated that the proposed market-oriented approach constructs a perfect competitive market in product distribution problem in SCM. A pareto optimal solution was acquired in product distribution problem by the metaphor of an economy in multi agent society, and that concludes the SCM based on market mechanism plays an important role in the coming agile manufacturing era.

Acknowledgements
This research has been supported by Intelligent Manufacturing System Programme of MITI (Ministry of International Trade and Industry), under contract No.9819 (HUTOP project). I thank Ms. Mieko Hirota in CEC Corp. for her dedicated work on this research.

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