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Full Length Research Paper

Development of an approach to coordinate the objectives for members of a supply chain

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Two important problems in a traditional supply chain are that the supply chain strategy is not fully integrated with a company's competitive strategy, and that supply chain members have their own different objectives that may adversely affect the performance of the whole chain. A supply chain and its members need to develop a supply chain strategy that fits well with the competitive strategies of each member, as this will decrease conflict among them. In order to address these two issues, an optimized approach is proposed in this research. This approach not only integrates the supply chain and company strategies, but also coordinates the various objectives among members to maximize supply chain performance. It provides a calculation of the objectives of the entire supply chain and those of individual members, so that they can evaluate their objective setting and performance while executing different value-added operations. The proposed approach is illustrated with a numeric example of a typical supply chain and followed by a case study as evidence of its effectiveness.

Key words: Supply chain management, competitive strategy, supply chain strategy.

INTRODUCTION

Supply chain management has become a key factor aiding companies to obtain competitive advantages (Handfield and Nichols, 1999). In order to achieve competitiveness, the first priority is to have a complete strategy which should be consistent with the company strategy for the whole supply chain. Chopra and Meindl (2007) noted that any company's success relies heavily on its integration of the supply chain strategy and its own strategy. However, in practice, many firms do not have a supply chain strategy, or if they do it is not in accordance with the company strategy. A survey of 258 high level managers in different industries by Harrison and New (2002) indicated that all the managers believed that supply chain strategy has an absolute relationship with the company strategy, while 92% believed that supply chain strategy is important or very important for competitive advantage. However, surprisingly, 58% of the companies surveyed either did not have a supply chain strategy or lacked a clear definition one.

Drucker (1998); Lambert and Cooper's (2000) examined the objective integration of supply chain members, and both stated that a supply chain's ultimate success relies wholly on whether it is capable of integrating the business relationships between supply chain members, and that in reality the members have conflicting objectives. Lee and Billington (1992) also noted that each supply chain member has its own objectives, which may be contradictory and, possibly, reduce the efficiency of the whole supply chain. For instance, a supply chain member might aim to decrease costs and thus decide to decrease their inventory. Meanwhile, the downstream firm may aim to increase its inventory to maintain its customer service quality. In this situation, the total cost may increase and confidence between members may decrease in the overall supply chain.

It is thus a key success factor for a supply chain and its members to build a supply chain strategy and to fit it with the company strategy, also to decrease the conflict among the objectives of various members. This research proposes an optimized approach which not only integrates the supply chain strategy and the company strategy, but also coordinates supply chain members' objectives and maximizes the supply chain performance with the aim of satisfying end-user needs. In addition, this

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approach provides a calculation of the objectives of the entire supply chain and those of individual members, so that they can evaluate their objective setting and performance while executing different value-added operations.

BASIC IDEA

Simchi-Levi et al. (2008) claimed that a whole supply chain can be optimized by applying the best strategy when facing market uncertainty. We thus propose a general approach to deal with different supply chain strategies and customer needs, and maximize the performance of the whole chain.

Definitions

In order to establish and explain the proposed approach, it is necessary to define the following terms:

(i) Value-added measures: measures that add value to the product or service. The added value could include time, quality and cost, etc.
(ii) Competitive measures: measures that are performed better than by competitors and thus help to gain orders are called competitive measures.
(iii) Value-added table (VAT): all the members of the supply chain should make this table, which states the relationships among the value-added measures that a member performs.

Min and Zhou (2002) stated that a supply chain is limited by three constraints, which are related to capacity, the extent of demand and service compliance. In addition, Christopher and Towill (2000) brought up the idea of market qualifiers and market winner based on the overall supply chain market view. This thesis integrates these constraints and measures and builds up a mathematical programming method with the limitations and objective equations defined as below:

(iv) Capacity constraint: this constraint occurs when a member of the supply chain is facing a limitation in their own capacity or resources when performing value-added activities for a product or service. This constraint has a maximum upper limit.

(v) Demand constraint: when a member of the supply chain is performing a value-added activity for the raw material or semi-product from the upper stream, the product or service should satisfy the constraints for the downstream value-added activity, such as a quality or lead time constraint.

(vi) Service promise constraint: this is the objective of the supply chain or end customer that needs to be met. Because the demand constraints of the lowest stream of the supply chain come from the supply chain end customer, the service promise constraint is a special case of the demand constraints.

The market qualifier proposed by Christopher and Towill (2000) is the same idea as service promise constraint proposed by Min and Zhou (2002); while the market winner is the same as the competitive measures in this paper. In order to use the terms consistently, these two measures will not be used in the paper, but only to support the theories and explain their correlation with the study.

Assumptions

The proposed approach is based on the following assumptions:

(i) Simchi-Levi et al. (2003) concluded that the success of supply chain optimization for National Semiconductor, Wal-Mart and P&G might because of their leading positions in their industries. Therefore, in this paper, we suggest the channel captain of the supply chain should be held by the most powerful member in the supply chain. The role of the channel captain is to plan the supply chain activities which include planning supply chain strategy; defining the market segment variables and dividing the whole market into several sub-market; analyzing each sub-market; selecting the target market and the new suppliers; building up supply chain and member objectives; communicating with each member of the supply chain; evaluating supply chain performance; coordinating profit and risk sharing.

(ii) Different products' supply chains consist of different supply chain members and channels, which also implies different organizational frameworks and functions. The channel captain should thus set up a supply chain network according to the needs of each product. They should collect from each member the related capacity constraints, demand constraints and the value-added table of each product. The channel captain should then calculate the objectives for the entire supply chain and each member for every specific product based on this data.

(iii) Some factors change from time to time, such as customer requirements, and internal and external conditions, and so the channel captain should regularly restart the calculation process of objective setting for the entire supply chain and each member. This study assumed that these variable factors and the supply chain environment are deemed to be stable between the prior objective setting and the next objective setting. In other words, when supply chain members are performing value-added activities for products or services, the competitive measures, capacity constraints, demand constraints, service promise constraints and value-added measures remain unchanged during the period.

(iv) The material transferring coefficient between members should be added to its upstream or downstream member according to the real status. For instance, when a product is been transferred from member A to member B, the value of this transferring activity (such as: cost, quality or time) should be added to member A or B's VAT.

(v) The attribute of each material/product from every member could be found in the linear or non-linear combination of a product's value-added activities carried out by the member itself and the upstream.

The approach

Jayaraman et al. (1999) noted that mathematical programming method always leads to the best outcome when dealing with different problems. Although mathematical programming method is unable to adapt non-quantitative criteria, it avoids some subjective judgments compared to other approaches. With conflicting objectives, Taylor (2004) proposed setting one of them as the objective function and the others as constraints in order to balance them. This study uses mathematical programming method and adapts the above mentioned assumptions. The competitive measure is set as the objective function and the value-added measure of every supply chain member set as the decision variable. The constraints are capacity constraints, demand constraints and service promise constraints of the supply chain members. After calculating the objective function value, the corresponding decision variables are the objective values for the supply chain members.

Beamon (1999) pointed out that most of the related studies evaluate supply chain performance based on four measures: cost, time, customer response and flexibility. Neely, Gregory and Platts (1995) claimed that it is unfeasible to evaluate all the performance measures of a system, and also proposed four measures to evaluate the performance of a manufacturing system: quality, time, cost and flexibility. Olhager and Selldin (2004) indicated that speed, flexibility, quality and cost are becoming increasingly important in the fast changing competitive environment. This study is supposed to be held between two objective setting, so the environment and the capacity of the supply chain are assumed to be stable, and therefore the performance measure of flexibility is not taken into consideration. In this research we consider three measures, cost, time and product quality, as value-added measures of the proposed approach. In practice, different industries can use different measures according to their specific environment. The approach proposed by this study is described in more detail below:

(1) Decision variable: the value-added measure of every supply chain member

(2) Objective function: optimize the combination of competitive measures of the final product for all the lowest stream members in a supply chain.

(3) Constraints:

(i) Capacity constraints of supply chain members;

(ii) Demand constraints of supply chain members;

(iii) Service promise constraints from the lowest stream members in a supply chain;

The notations used in the mathematical programming approach based on the aforementioned conditions are as follows:

Notation:

t_i: The capacity of time value for member i of the supply chain.

q_i: The capacity of quality value for member i of the supply chain.

c_i: The capacity of cost value for member i of the supply chain.

x_i: The capacity of competitive measure value for member i of the supply chain, x stands for the competitive measure, and could be t, q or c.

$f(x_i)$: The combination of competitive measures of a product for member i of the supply chain.

m: The set of the lowest stream of members of the supply chain.

n: The set of all the members of the supply chain.

T_i: The constraint of time for member i of the supply chain.

Q_i: The constraint of quality for member i of the supply chain.

C_i: The constraint of cost for member i of the supply chain.

$g(t_i)$: The combination of time values in the value-added measure for the product of member i of the supply chain.

$g(q_i)$: The combination of quality values in the value-added measure for the product of member i of the supply chain.

$g(c_i)$: The combination of cost values in the value-added measure for the product of member i of the supply chain.

A_i: Time demand from the direct downstream members of member i of the supply chain.

B_i : Quality demand from the direct downstream members of member i of the supply chain.

G_i: Cost demand from the direct downstream members of member i of the supply chain.

D_i: Time demand from customers of member i of the supply chain.

E_i: Quality demand from customers of member i of the supply chain.

F_i: Cost demand from customers of member i of the supply chain.

Objective functions:

$$\text{Min. (Max.)} \sum_{I \in M} F(X_I) .$$

This objective function attempts to get the minimum/ maximum value of the sum of competitive measure of the final product from all the lowest stream members of the

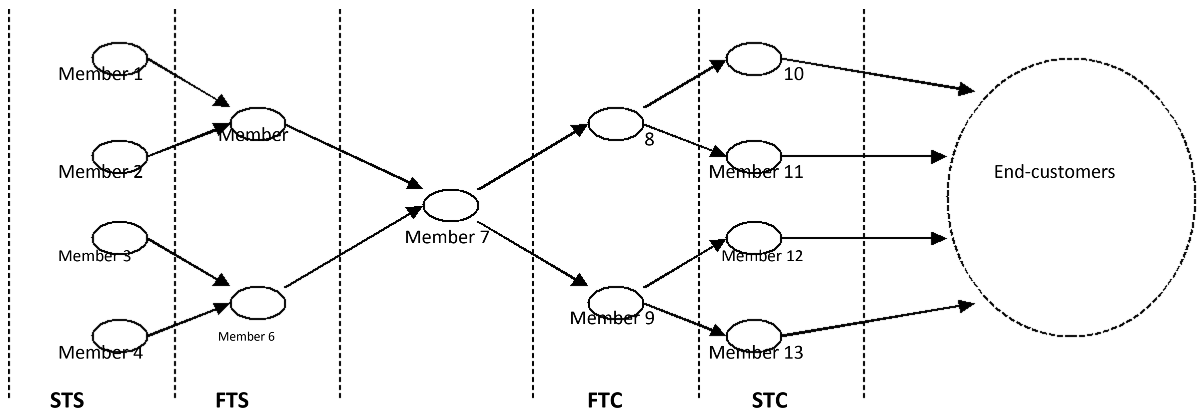

Figure 1. A general supply chain network (Lambert et al., 1998). Notes: FTS: First tier supplier, STS: Second tier supplier, FTC: First tier customer, STC: Second tier customer, EC: Member 7: Channel captain.

members of the supply chain.

Constraints:

1. The capacity constraints of supply chain members.

$t_i \geqq T_i$, $i \in n$. (1)

$q_i \leqq Q_i$, $i \in n$. (2)

$c_i \geqq C_i$, $i \in n$. (3)

2. The demand constraints of supply chain members.

$g(t_i) \leqq A_i$, $i \in (n-m)$. (4)

$g(q_i) \geqq B_i$, $i \in (n-m)$. (5)

$g(c_i) \leqq G_i$, $i \in (n-m)$. (6)

3. Service promise constraints from the lowest stream members of a supply chain.

$g(t_i) \leqq D_i$, $i \in m$. (7)

$g(q_i) \geqq E_i$, $i \in m$. (8)

$g(c_i) \leqq F_i$, $i \in m$. (9)

As the supply chain network and operation are complex, the objective function or the constraints will lead to a decision variable of linear or non-linear combination. The efficiency of a general optimized approach is not acceptable. Therefore, a heuristic method is preferred, such as Simulated Annealing, the Ant Algorithm and the Genetic Algorithm. The Genetic Algorithm is used in this paper to get the optimal or near optimal solution of the objective function and the decision variable. This is a heuristic algorithm developed by Holland (1975) and is a fitness-based process and an optimal search technique. It is basically inspired by evolutionary biology and the natural rule of survival of the fittest. It selects the best individuals from the first generation and conducts a random and repeated exchange of genetic messages in order to produce a better child generation. Although this method cannot ensure the best solution, and has a high operational cost and few applicable software packages, it still has many advantages, such as it can produce explainable results which are also ready for applications and can deal with a wide range of data. Most importantly, compared to other heuristic methods, it can avoid being trapped in a locally optimal solution and will instead obtain the globally near-optimal solution.

NUMERIC EXAMPLE

This study uses a typical supply chain network, as shown in Figure 1 and discussed in Lambert et al. (1998), as an example to illustrate the proposed approach. In this example, the supply chain has thirteen members (Members 1-13). The terminal members in the supply chain are Members 10-13. Value-added measures are operation time (T_i), operation quality (Q_i) and operation cost (C_i) for supply chain member *i,* and they are also the decision variables in the following model. The target market is a market with customers who focus on product price, and thus the competitive measure is set as the cost measure and the objective function is the minimum total cost of the end product in the supply chain, as shown in Equation (1). Equations (2 to 30) show various constraints of our supply chain model for our example.

Objective function:

Min $(C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_8+ C_{10})+(C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+C_8+ C_{11})+(C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+C_9+C_{12})+(C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_9+C_{13})$ (1)

Subject to:

(1) Capacity constraints:

Member 1: $T_1 \geqq 1$, $Q_1 \leqq 3$, $C_1 \geqq 1$ (2)

Member 2: $T_2 \geqq 1$, $Q_2 \leqq 3$, $C_2 \geqq 3$ (3)

Member 3: $T_3 \geqq 2$, $Q_3 \leqq 3$, $C_3 \geqq 2$ (4)

Member 4: $T_4 \geqq 1, Q_4 \leqq 3, C_4 \geqq 1$ (5)

Member 5: $T_5 \geqq 2$, $Q_5 \leqq 2$, $C_5 \geqq 2$ (6)

Member 6: $T_6 \geqq 1$, $Q_6 \leqq 3$, $C_6 \geqq 3$ (7)

Member 7: $T_7 \geqq 2$, $Q_7 \leqq 3$, $C_7 \geqq 4$ (8)

Member 8: $T_8 \geqq 1$, $Q_8 \leqq 2$, $C_8 \geqq 2$ (9)

Member 9: $T_9 \geqq 2$, $Q_9 \leqq 3$, $C_9 \geqq 2$ (10)

Member 10: $T_{10} \geqq 1$, $Q_{10} \leqq 3$, $C_{10} \geqq 1$ (11)

Member 11: $T_{11} \geqq 1$, $Q_{11} \leqq 3$, $C_{11} \geqq 1$ (12)

Member 12: $T_{12} \geqq 1$, $Q_{12} \leqq 3$, $C_{12} \geqq 2$ (13)

Member 13: $T_{13} \geqq 1$, $Q_{13}3$, $C_{13}1$ (14)

(2) Demand constraints:

Member 1: T_14, Q_12, C_18 (15)

Member 2: T_23, Q_21, C_28 (16)

Member 3: T_33, Q_31, C_38 (17)

Member 4: T_43, Q_41, C_46 (18)

Member 5: Max $(T_1, T_2) + T_58$, $(Q_1+Q_2)*Q_52$, $C_1+ C_2+ C_531$ (19)

Member 6: Max $(T_3, T_4) + T_67$, $(Q_3+Q_4)*Q_62$, $C_3+ C_4+ C_625$ (20)

Member 7: Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_713$ $(((Q_1+Q_2)*Q_5)+(Q_3+Q_4)*Q_6)*Q_74C_1 +C_2 +C_3+ C_4+ C_5+ C_6+ C_770$ (21)

Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_714$ $(((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6)*Q_74C_1+C_2+C_3+C_4+C_5+C_6+C_769$ (22)

Member 8: Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7+ T_816$ $((((Q_1+Q_2)*Q_5) + (Q_3+Q_4)*Q_6)*Q_7)* Q_84$ $C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_8 \leqq 71$ (23)

Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7+ T_8 \leqq 17$ $((((Q_1+Q_2) *Q_5)+(Q_3+Q_4) *Q_6)*Q_7)*Q_8 \geqq 4C_1+ C_2+ C_3+C_4+ C_5+ C_6+ C_7+ C_8 \leqq 72$ (24)

Member 9: Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7+ T_9 \leqq 16$ $((((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6) *Q_7)*Q_9 \geqq 4$ $C_1+C_2+C_3+C_4+C_5+C_6+C_7+C_9 \leqq 78$ (25)

Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7+ T_917$ $((((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6) *Q_7)*Q_94$ $C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_979$ (26)

(3) Service compliance constraints:

Member 10: Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7+ T_8+ T_{10}19$ $(((((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6) *Q_7)*Q_8)* Q_{10}4$ $C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_8+ C_{10}82$ (27)

Member 11: Max (Max $(T_1, T_2)+ T_5$, Max $(T_3, T_4)+ T_6)+ T_7+ T_8+ T_{11}19$ $(((((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6) *Q_7)*Q_8) *Q_{11}4$ $C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_8+ C_{11}82$ (28)

Member 12: Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7+ T_9+ T_{12} \leqq 21$ $(((((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6) *Q_7)*Q_9)* Q_{12} \geqq 4$ $C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_9+ C_{12} \leqq 84$ (29)

Member 13: Max (Max $(T_1, T_2) + T_5$, Max $(T_3, T_4) + T_6) + T_7 + T_9 + T_{13} \leqq 21$ $(((((Q_1+Q_2)*Q_5) +(Q_3+Q_4)*Q_6) *Q_7)*Q_9)* Q_{13} \geqq 4$ $C_1+ C_2+ C_3+ C_4+ C_5+ C_6+ C_7+ C_9+ C_{13} \leqq 84$ (30)

This example assumes that the measures of cost, quality, and time should obey the following rules. The cost measure of the end-product in the supply chain is the sum of the cost measures of all members. For instance, the final product cost of Member 10 is the sum of all the operation costs added from Members 1 to 8 and 10. The quality measure of the end-product is the product or sum of the quality measures of all members, depending on the levels of the members. If members are at the same level, their combined quality measure is the sum of the quality measures of these members; if they are at different levels, their combined quality measure is the product of their quality measures. For example, Members 1 and 2 are at the same level and both suppliers of Member 5, and so their combined quality measure is the sum of each quality measure. Members 8 and 10 are at different levels, and so their combined quality measure is the product of their quality measures. The time measure of an end-product is the sum of the maximal time measures from each level. The basic concept is that members in the supply chain can not start their operation until all their suppliers have finished their operations. We always select the maximal operation time from all members at the same level as the level operation time. For instance, the operation time of Members 1 and 2 is 4 and 3, respectively, and so the level operation time is 4.

Each member in the supply chain has their own capacity constraint; Equations (2) to (14) show the constraints of Members 1 to 13, respectively. Equation (2) indicates that Member 1 has the following constraints: operation time must be greater than or equal to one time unit, operation quality must be less than or equal to three quality units, and operation cost must be greater than or equal to one cost unit. All numbers shown here has been normalized for simplicity. Equations (15) to (26) show the demand constraints of Members 1 to 9. Each of Members 7 to 9 has two downstream members, and thus each has two sets of (T,Q,C) demand constraints; for example, Member 9 has two downstream members 12 and 13, constraint (25) is for Member 12 and constraint (26) is for Member 13. Equations (27) to (30) show the service compliance constraints for the four terminal members 10 to 13, respectively. Each member has their own VAT table, as shown in Table 1 for Members 1 to 13.

Genetic algorithm approach

GA consists of a population size (PS) of individuals competing on a survival-of-the-fittest basis. The algorithm proceeds in steps called generations. During each generation, a new PS of individuals is created from the old via application of genetic operators, and evaluated as solutions to a given problem (the environment). Due to selective pressure, the population adapts to the environment over succeeding generations, evolving better solutions.

This study uses the integer-coded approach. A GA process includes three operators: reproduction, crossover, and mutation. Reproduction is a process in which bad chromosomes in PS are replaced by the best ones. In this study, any chromosome with a fitness value which is higher than the average value of all chromosomes will be replaced by the one with the best fitness value. Crossover is a process in which a pair of chromosomes randomly exchanges part of their genes to form two new chromosomes. First, we select chromosomes from the PS based on crossover rate (CR). Then, in these selected chromosomes, we randomly form pairs to perform crossover. Mutation is a process in which the genes of selected chromosomes mutate randomly. The selection from PS is based on a mutation rate (MR).

Table 1. VAT table of supply chain members.

Member 1			Member 2			Member 3			Member 4			Member 5			Member 6			Member 13		
T_1	Q_1	C_1	T_2	Q_2	C_2	T_{13}	T_{13}	T_{13}	T_4	Q_4	C_4	T_5	Q_5	C_5	T_6	Q_6	C_6	T_{13}	Q_{13}	C_{13}
4	1	5	3	1	2	3	3	3	3	1	1	4	1	3	3	1	3	3	1	1
4	2	6	3	2	3	3	3	3	3	2	2	4	2	5	3	2	4	3	2	2
4	3	8	3	3	5	3	3	3	3	3	3	4	3	7	3	3	5	3	3	3
3	1	7	2	1	3	2	2	2	2	1	2	3	1	5	2	1	5	2	1	2
3	2	9	2	2	5	2	2	2	2	2	3	3	2	6	2	2	6	2	2	4
3	3	10	2	3	6	2	2	2	2	3	5	3	3	8	2	3	8	2	3	5
2	1	10	1	1	5	1	1	1	1	1	3	2	1	6	1	1	6	1	1	4
2	2	12	1	2	7	1	1	1	1	2	5	2	2	7	1	2	8	1	2	5
2	3	14	1	3	8	1	1	1	1	3	6	2	3	9	1	3	9	1	3	6

Member 7			Member 8			Member 9			Member 10			Member 11			Member 12		
T_7	Q_7	C_7	T_8	Q_8	C_8	T_9	Q_9	C_9	T_{10}	Q_{10}	C_{10}	T_{11}	Q_{11}	C_{11}	T_{12}	Q_{12}	C_{12}
5	1	8	3	1	2	4	1	2	3	1	1	3	1	1	3	1	1
5	2	10	3	2	3	4	2	3	3	2	2	3	2	2	3	2	2
5	3	11	3	3	4	4	3	4	3	3	3	3	3	3	3	3	3
4	1	9	2	1	3	3	1	3	2	1	2	2	1	2	2	1	3
4	2	12	2	2	4	3	2	5	2	2	4	2	2	3	2	2	4
4	3	13	2	3	6	3	3	7	2	3	5	2	3	4	2	3	5
3	1	11	1	1	4	2	1	5	1	1	3	1	1	3	1	1	4
3	2	13	1	2	5	2	2	6	1	2	5	1	2	4	1	2	5
3	3	15	1	3	7	2	3	8	1	3	6	1	3	5	1	3	6

This study uses the software Evolver 4.0.6 (1998) to perform the genetic algorithm operations. The fitness function is the objective function. The chromosome is formed by the time and quality of all members in the supply chain. Uniform crossover and uniform mutation schemes are used. PS = 50, CR = 0.5, and MR = 0.1. The stopping condition is set when a change between generations is less than 0.01% for the subsequent 100 generations.

RESULTS AND DISCUSSION

Under the conditions and constraints of the example shown above, the results shown in Table 2 are produced. The table shows that the value-added measures are the objectives for the supply chain members. The objective values for members 1 to 13 are (3, 2, 5), (3, 2, 3), (3, 1, 4), (3, 1, 1), (4, 1, 3), (3, 1, 3), (5, 1, 8), (3, 1, 2), (4, 1, 2), (3, 1, 1), (3, 1, 1), (3, 2, 2) and (3, 1, 1), respectively, the values between brackets stand for time, quality and cost. Table 2 also indicates the objectives for the supply chain. For the lowest stream members, namely 10, 11, 12 and 13, the objectives are (18, 6, 30), (18, 6, 30), (19, 12, 31) and (19, 6, 30), respectively. In this case, there are four objectives for the supply chain, this is because when raw materials or semi-products pass through different supply chain members, every member reacts with different needs and value-added capacity, and the four lowest stream members of the supply chain have different customer needs.

In this example, the target market is a market with customers who focus on product price; consequently, the competitive measure is set as the cost measure and the objective function is the minimum total cost of the end product in the supply chain. However, the proposed approach is flexible and applicable and therefore it could be extended to another competitive measure, such as quality, time, or other factors.

Case study

A real case of a three-tiered supply chain is introduced in this section, and the proposed approach is used for an empirical study. The section consists of two parts, the first introduces the supply chain conditions and members' backgrounds, and the second builds the model and applies it to the supply chain in question.

Introduction of the supply chain conditions and members backgrounds

The supply chain in question is a real case in Taiwan. Member 1 is a professional contract manufacturer of office use lamps, Member 2 is a manufacturer and also

Table 2. Objective values for the supply chain.

Competitive measure	Objective function value	Value-added objectives for each member				The objectives for the supply chain			
		Member	T	Q	C	Member	T	Q	C
		1	3	2	5				
		2	3	2	3	10	18	6	30
		3	3	1	4				
		4	3	1	1				
		5	4	1	3	11	18	6	30
		6	3	1	3				
Cost	121	7	5	1	8				
		8	3	1	2	12	19	12	31
		9	4	1	2				
		10	3	1	1				
		11	3	1	1	13	19	6	30
		12	3	2	2				
		13	3	1	1				

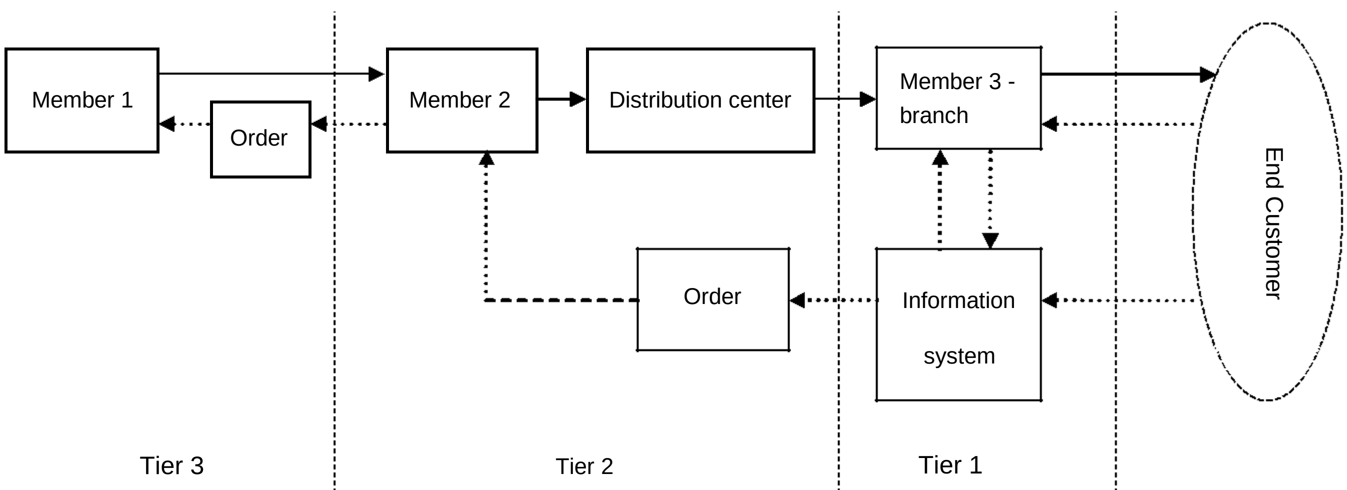

Figure 2. Supply chain network for the case study. Solid line: Logistics; Information.

owner of multiple branded products, some of which are outsourced for production. In this case, one of their well-known brands of lamp is outsourced to Member 1 for production. Member 3 is a large retailer, mainly selling house wares and furnishings. These three members compose a supply chain network, shown in Figure 2. The end customer can purchase the product from any branch store of Member 3 or order directly through its internet services. When Member 3 has accumulated a certain amount of demand, they will place an order with Member 2. Member 2 places an order with Member 1 based on needs estimation. In practice, Member 2 proposes to Member 1 the needs estimation for the next three months at the beginning of every month. Data analysis indicates the accuracy for the first month is 100%, and both members agree that the estimation of first month should be the real quantity ordered. The analysis then indicates 90% accuracy for the second month, and 78% for the third month. When estimating needs for the next three months, the members will also adjust the previously estimated values. At the beginning of every month, Member 2 regularly collects from Member 1 50 to 70% of the estimated quantity of products. Member 1 thus produces lamps based on the order from Member 2, who then delivers them via their own logistics operations to Member 3's branch stores. If customers order online, then Member 3's branch stores will deliver the goods to the customer, who will be charged the extra transportation cost. In this case, as Member 2 owns a well-known and high-priced branded lamp, they take the predominant

Table 3. Activities and related data for Member 1.

Scenario	Criteria	Procurement	Manufacturing	Warehousing+ inventory	Delivery	Total
	Time (days)	35	10	15	1	61
(1)	Quality (yield rate; %)	97				
	Cost (NTD)	520	70	130	10	730
	Time (days)	25	10	15	1	51
(2)	Quality (yield rate; %))	97				
	Cost (NTD)	624	70	130	10	834
	Time (days)	45	10	15	1	71
(3)	Quality (yield rate; %))	95				
	Cost (NTD)	520	90	130	10	750
	Time (days)	35	15	15	1	66
(4)	Quality (yield rate; %))	93				
	Cost (NTD)	520	93	130	10	753
	Time (days)	35	15	30	1	81
(5)	Quality (yield rate; %))	95				
	Cost (NTD)	520	70	234	10	834

position in the supply chain, and thus plan the supply chain strategy, that the others follow.

Model building

Porter (1980) suggested three organizational competitive strategies, namely low cost, differentiation and concentration. The predominant company in the case study supply chain originally adopted a differentiation strategy, with the quality of the product prioritized over other strategies. However, due to the global economy, the company decided to change to a low cost strategy, while still maintaining a certain quality level. Consequently, the supply chain strategy as well as other supply chain members' objectives are also adjusted accordingly. According to the above mentioned supply chain model building and considering the three members of the supply chain, we collect related information and built the criteria listed thus:

1. Time: This includes the operation time for all value-added activities, such as procurement, manufacturing, inventory, delivery and marketing. The complete operation time for a member is the time they take to achieve all the value-added activities for the product. Member 1 is a contract manufacturer, and their operation time includes procurement, manufacturing, warehousing, inventory and delivery; Member 2 is the brand owner, and their operation time mainly consists of inventory and delivery; Member 3 is a channel retailer, and their operation time includes inventory and delivery.
2. Quality: This is evaluated by yield rate. The product yield rate is the quantity of qualified products divided by the total quantity produced. When a member is performing any value-added activity for the product, it will possibly impact the yield rate. For instance, the extension of inventory or delivery time could reduce the yield rate. Therefore, as the value-added activities persist and the time continues, the yield rate tends to reduce progressively.
3. Cost: This consists of the operational cost of procurement, manufacturing, warehousing, inventory, delivery, marketing and store management. The complete operation cost for a member is the cost they bear for all their value-added activities. For Member 1, it thus includes the cost of procurement, manufacturing, warehousing, inventory and delivery; for Member 2, it includes warehousing, inventory, delivery and marketing cost; and for Member 3, warehousing, inventory and store management.

The details of all the value-added activities for Members 1, 2 and 3 are listed in Tables 3, 4 and 5, respectively. Table 3 indicates the five operation scenarios with average values for Member 1, which are as follows:

1. In general, the standard lead time is 61 days since Members 2 and 1 negotiate the price. Member 1 takes 35 days for procurement, 10 days for manufacturing, 15 days for warehousing and inventory, and one day for delivery, which makes a total of 61 days. The product yield rate is 97%. The procurement cost is $520, the manufacturing cost is $70, the cost for warehousing and inventory is $130, and $10 for delivery cost, so the total cost will be $730.

Table 4. Activities and related data for Member 2.

Scenario	Criteria	Warehousing + inventory	Delivery	Marketing	Total
	Time (days)	10	3		13
(1)	Quality (yield rate; %)	99			
	Cost (NTD)	270	50		320
	Time (days)	10	6		16
(2)	Quality (yield rate; %))	98			
	Cost (NTD)	270	60	33	363
	Time (days)	5	4		9
(3)	Quality (yield rate; %))	98			
	Cost (NTD)	162	60	26	248

Table 5. Activities and related data for Member 3.

Scenario	Criteria	Warehousing + inventory	Store management	Total
	Time (days)	48		48
(1)	Quality (yield rate; %)	97		
	Cost (NTD)	470	463	933
	Time (days)	25		25
(2)	Quality (yield rate; %))	96		
	Cost (NTD)	329	463	792
	Time (days)	62		62
(3)	Quality (yield rate ; %)	92		
	Cost (NTD)	846	463	1309

2. In this case, Member 2 asks Member 1 for earlier delivery. To meet Member 2's requirement, Member 1 imports the raw materials by air instead of sea, reducing the procurement time, but increasing the procurement cost. The procurement time thus becomes 25 days, the manufacturing time 10 days, warehousing and inventory takes 15 days, and one day for delivery, which makes the total time 51 days. The product yield rate is 97%. The procurement cost is $624, the manufacturing cost is $70, the cost for warehousing and inventory is $130, and $10 for delivery cost, so the total cost will be $834.

3. In this case, Member 1 realizes the materials imported have some defects and so return them and they are re-delivered. Therefore, the procurement time will increase, but the cost remains the same. The procurement time becomes 45 days, the manufacturing time is 10 days, warehousing and inventory takes 15 days, and one day for delivery, which makes the total time 71 days. The product yield rate is 95%. The procurement cost is $520, the manufacturing cost is $90, the cost for warehousing and inventory is $130, and $10 for delivery cost, so the total cost will be $750.

4. In this case, the productivity is insufficient so the manufacturing time increases. The procurement time becomes 35 days, the manufacturing time becomes 15 days, warehousing and inventory takes 15 days, and one day for delivery, which makes the total time 66 days. The product yield rate is 93% (due to overtime working). The procurement cost is $520, the manufacturing cost is $93, the cost for warehousing and inventory is $130, and $10 for delivery cost, so the total cost will be $753.

5. In this case, the demand falls, which causes increases in inventory and warehousing costs? The procurement time is 35 days, the manufacturing time becomes 15 days, warehousing and inventory takes 30 days, and one day for delivery, which makes the total time 81 days. The product yield rate is 95% (due to the longer inventory time). The procurement cost is $520, the manufacturing cost is $70, the cost for warehousing and inventory becomes $234, and $10 for delivery cost, so the total cost will be $854.

Table 4 indicates the three operation scenarios with average values for Member 2. Different to other members, Member 2 has an automatic warehouse system for the goods.

Table 6. The VAT tables for the supply chain members of the case study.

Member 1 value-added measures			Member 2 value-added measures		
Time (days)	Quality (yield rate) (%)	Cost (NTD)	Time (days)	Quality (yield rate) (%)	Cost (NTD)
61	97	730	13	99	320
51	97	834	16	98	363
71	95	750	9	98	248
66	93	753			
81	95	834			
Member 3 value-added measures					
Time (days)	**Quality (yield rate) (%)**	**Cost (NTD)**			
48	97	933			
25	96	792			
62	92	1309			

1. In general, Member 2 takes 10 days for warehousing and inventory and three days for delivery to all branch stores of Member 3, so the total time is 13 days. The product yield rate is 99%. The cost for warehousing and inventory is $270, and $50 for delivery, so the total cost is $320.
2. In this case, Member 2 undertakes product promotion mainly focusing on TV commercials, which causes some additional marketing costs. The warehousing and inventory takes 10 days and six days for delivery, so the total time is 16 days. The product yield rate is 98%. The cost for warehousing and inventory is $270, $60 for delivery, and $33 for marketing costs, so the total cost is $363.
3. Now Member 2 is at the final phase of the promotional period, the number of TV commercials is reducing, and the supply is insufficient at this phase. Without considering the short supply cost, the warehousing and inventory take five days, and four days for delivery, so the total time is nine days. The product yield rate is 98%. The cost for warehousing and inventory is $162, $60 for delivery, and $26 for marketing costs, so the total cost is $248.

Table 5 indicates the three operation scenarios with average values for Member 3:

1. In general, Member 3 takes 48 days for warehousing and inventory, since Member 3 itself is the warehouse and retailer, so the total time is 48 days. The product yield rate is 97%. The cost for warehousing and inventory is $470, and the store management cost is $463, so the total cost is $933.
2. In this case, Member 3 offers a price reduction. The warehousing and inventory takes 25 days, so the total time is also 25 days. The product yield rate is 96%. The cost for warehousing and inventory is $329, the store management cost is $463, so the total cost is $792.
3. Now comes the slow-selling period, and warehousing and inventory takes 62 days, which is also the total time. The product yield rate is 92%, due to the longer storage time and misplacement of goods. The cost for warehouse and inventory is $846, the store management cost is $463, so the total cost is $1,309. As Member 3 is about to lose money, in order to reduce the deficit, they will sometimes return goods back to Member 2 as defective.

After consolidating Tables 3, 4 and 5, we can generate the VAT tables for Members 1, 2 and 3, as shown in Table 6.

The final product's value combination is as follows. The time is the sum of the operation time for all members; as regards the quality, according to the past data, the yield rate of the product is close to the product of the yield rate of the three tiered members; the cost is the sum of cost from the three members. Every member is limited by their own capacity and their demand constraints with regard to the downstream member. The case study case supply chain aims to lower the total supply cost while satisfying the end customer's requirements. By reviewing the capacity constraints from every member, the demand constraints toward their downstream member, service promise constraints toward the end customer, and the VAT table of every member, the following mathematical model is built:

Decision variables: T_i, Q_i, and C_i, i = 1 to 3
Objective function: Min $C_1 + C_2 + C_3$ (31)

Subject to:

(1) Capacity constraints of supply chain members:

Member 1: $T1 \geqq 40$, $Q1 \leqq 0.99$, $C1 \geqq 720$ (32)
Member 2: $T2 \geqq 9$, $Q2 \leqq 0.99$, $C2 \geqq 245$ (33)
Member 3: $T3 \geqq 23$, $Q3 \leqq 0.98$, $C3 \geqq 785$ (34)

Table 7. All the values for the supply chain (Cost).

Competitive measure index	Objective function value (NTD)	Value-added objectives for each member				Objective value for final product		
		Member no.	Time (day)	Quality (yield rate)	Cost (NTD)	Time (day)	Quality (yield rate)	Cost (NTD)
Cost	1,770	1	61	0.97	730	95	0.91	1770
		2	9	0.98	248			
		3	25	0.96	792			

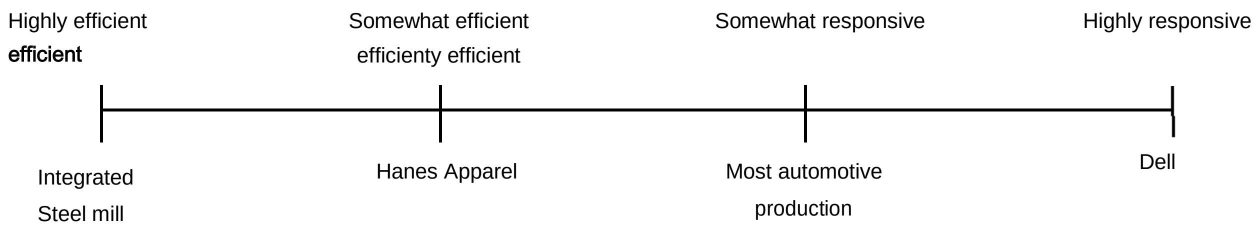

Figure 3. Responsiveness spectrum by industry (Chopra and Meindl, 2007).

(2) Demand constraints of supply chain members:

Member 1: $T1 \leqq 85$, $Q1 \geqq 0.92$, $C1 \leqq 870$ (35)

Member 2: $T1+T2 \leqq 98$, $Q1*Q2 \geqq 0.91$, $C1+C2 \leqq 1230$ (36)

(3) The service promise constraints of the member of the lowest stream:

Member 3: $T1+T2+T3 \leqq 160$ (37)

$Q1*Q2*Q3 \geqq 0.89$ (38)

$C1+C2+C3 \leqq 2165$ (39)

This model aims to minimize the total cost for the final product, so, as shown in (31), we ask for the minimum of the sum of the cost from the three members. In addition, every member is limited by their own capacity constraints while performing value-added activities. For Member 1, the time should be more than or equal to 40 days, the yield rate should be less than or equal to 99%, the cost should be bigger than or equal to $720. For Member 2, the time should be longer than or equal to nine days, the yield rate should be less than or equal to 99%, the cost should be more than or equal to $245. For Member 3, the time should be more than or equal to 23 days, the yield rate should be less than or equal to 98%, the cost should be more than or equal to $785. The capacity constraints for each member are shown as (32) to (34). In addition, every member should meet their downstream member's demand. For Member 1, the time should be less than or equal to 85 days, the yield rate should be more than or equal to 92%, the cost should be less or equal to $870. For Member 2, the time should be less than or equal to 98 days, the yield rate should be more or equal to 0.91, the cost should be less or equal to $1,230. The demand constraints for each member are shown in (35) and (36). Finally, the service promise constraints for the member of the lowest stream (Member 3) should meet end customer's needs: the time should be less or equal to 160 days, the yield rate should be more or equal to 0.89, the cost should be less or equal to $2,165. The service promise constraints for Member 3 are shown in (37) to (39).

In this case study, the objective function is converted into the adaptation function of GAs using Evolver version 4.0.6 (1998). The parameter setting in the software is as follows: Population size is set as 50, crossover rate as 0.5, mutation rate as 0.2, and the stopping conditions as the change in the last 100 valid trials is less than 1%. Under these conditions and parameters, the values shown in Table 5 are produced. Table 7 shows the value-added measures are the objective

Table 8. All the values for the supply chain (Time).

Competitive measure	Objective function (days)	Value-added objectives for each member				Objective value for final product		
		Member no.	Time (days)	Quality (yield rate)	Cost (NTD)	Time (days)	Quality (yield rate)	Cost (NTD)
Time	85	Member 1	51	0.97	834	85	0.91	1874
		Member 2	9	0.98	248			
		Member 3	25	0.96	792			

objective values for the supply chain members. The objective values for member 1 is (61, 0.97, 730), for member 2 is (9, 0.98, 248), for member 3 is (25, 0.96, 792), and the values between brackets stand for time (day), quality (yield rate) and cost (NTD). Table 7 also indicates the objective value for the final product, which is (95, 0.91, 1770). This means that from the day that Member 1 receives an order and starts the procurement process till the day they deliver the product to the customer, the total time is 95 days, the yield rate should be 91%, and the cost of production is $1,770.

Management implications

Chopra and Meindl (2007) stated that to fulfill customer needs a supply chain should make a trade-off between responsiveness and efficiency. For a strategy emphasizing responsiveness, the cost will be increased and efficiency reduced. How-ever, by de-emphasizing responsive productivity, the cost will be lowed and efficiency will be improved. Furthermore, due to the diversity of products from different industries, supply chains from different industries will adopt different strategy. Figure 3 indicates the responsiveness spectrum by industry (Chopra and Meindl, 2007).

In the responsiveness spectrum, an integrated steel mill belongs to a highly efficient industry, and it must prearrange the production process every week or month with few changes or elasticity. Hanes Apparel is somewhat efficient and is a traditional manufacturer that reserves stock and needs a couple of weeks for production lead time. Most automotive production is somewhat responsive, as it mostly delivers diverse products in two weeks. Dell is highly responsive, and must complete a customized personal computer and deliver it in a couple of days. A supply chain strategy must thus consider the characteristics of the industry where it belongs, as well as the competitive strategy of the channel captain.

The approach proposed in this work is able to design supply chain strategies for different industries. The case study aims to lower the cost to reach better efficiency. But if the company changes the strategy to be more responsive and shorten the lead time, while other conditions remaining the same, we can generate all the values shown in Table 8. Table 8 shows that the objective values for member 1 are (51, 0.97, 834), for member 2 (9, 0.98, 248), and for member 3 (25, 0.96, 792), with the values between brackets standing for time (days), quality (yield rate) and cost (NTD). Table 8 also indicates the objective value for the final product, which is (85, 0.91, 1874). This means that from the day that Member 1 receives an order and starts procurement process till the day they deliver the product to the customer, the total takes 85 days, the yield rate should be 91% and the cost of production is $1,874.

The supply chain stressed efficiency, so the objective values resulting for the whole chain and all the members aim to lower the cost and reduce the responsiveness; whereas in this section, the focus is on responsiveness, and the objective values will assist in shortening the lead time and reducing the efficiency. The results also imply that when a supply chain is facing changes in internal resources, external conditions or customer needs, an immediate strategy adjustment as well as the re-initiation of objective setting for the whole supply chain and all members is required in order to capture the market opportunities.

Conclusions

In an industry with multiple competitors, a company should fit its supply chain strategy with its overall competitive strategy. IBM and Apple are two companies with different concepts and cultures. A member of IBM's supply chain should set objectives according to the concept of "Think Big", whereas a member of Apple's supply chain should set objectives based on the concept of "Think Different". Members of supply chains serving these two companies, even producing a same product, might thus have different objective settings. This work uses a mathematical programming method to deal with the related problems in supply chain. It first defines the terms used, describes the assumptions made, builds the approach and finally uses a Genetic Algorithm to coordinate supply chain members' objectives on the premise that a supply chain strategy should fit the firm's competitive strategy. A numeric example of a typical supply chain is used in this work to explain the proposed approach and a real case in Taiwan is examined. This approach can thus apply to different industries, assist in moderating conflicts between supply chain members, maximize supply chain performance and, most importantly, capture more competitive advantages.

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