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Integrated Supply Chain Model of Advanced Planning and Scheduling (APS) and Efficient Purchasing for Make-To-Order Production

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주문생산을 위한 APS 와 효율적 구매의 통합모델

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Abstract

This paper considers that advanced planning and scheduling (APS) in manufacturing and the efficient purchasing where each customer order has its due date and multi-suppliers exit. We present a Make-To-Order Supply Chan (MTOSC) model of efficient purchasing process from multi-suppliers and APS with outsourcing in a supply chain, which requires the absolute due date and minimized total cost.

Our research has included two states. One is for efficient purchasing from suppliers: (a) selection of suppliers for required parts; (b) optimum part lead-time of selected suppliers. Supplier selection process has received considerable attention in the business-management literature. Determining suitable suppliers in the supply chain has become a key strategic consideration. However, the nature of these decisions usually is complex and unstructured. These influence factors can be divided into quantitative and qualitative factors. In the first level, linguistic values are used to assess the ratings for the qualitative factors such as profitability, relationship closeness and quality. In the second level a MTOSC model determines the solutions (supplier selection and order quantity) by considering quantitative factors such as part unit price, supplier's lead-time, and storage cost, etc.

The other is for APS: (a) selection of the best machine for each operation; (b) deciding sequence of operations; (c) picking out the operations to be outsourcing; and (d) minimizing makespan under the due date of each customer's order. To solve the model, a genetic algorithm (GA)-based heuristic approach is developed. From the numerical experiments, GA-based approach could efficiently solve the proposed model, and show the best process plan and schedule for all customers' orders.

Key words: Make-To-Order Supply Chan (MTOSC), Advanced Planning and Scheduling (APS), *Outsourcing, Due date*

1. Introduction

Supply chains, which manufacture investment goods, consist of many successive business units, such as purchasing from suppliers, delivery, fabrication and assembly. In a supply chain environment, one manufacturing problem is that a number of customer-specific orders must be manufactured in a multi-project type of environment. Multiple customer-specific orders are subject to tight due dates, while at the same time there are long makespans, which result from order-specific parts that have to be manufactured in-house or produced outside. Capacity is generally scarce because fixed-cost has been reduced by outsourcing in recent years (Kolisch, 2000).

In a flexible industrial process, each order involves a different set of jobs in the fabrication and assembly process. The operations involved in a job are interrelated by precedence constraints, and can use alternative machines. Capacity adjustment is also possible through outsourcing with subcontractors when due dates cannot be kept. Timely and reliable delivery of products is an important factor in the manufacturing supply chain to ensure that manufacturing companies remain competitive. In some industries, meeting due dates is the bottom line for survival (Chung et al., 2000).

APS is very important in this environment, because it is at the leading edge of manufacturing management application technology. APS includes a range of capabilities, from finite-capacity scheduling at the shop floor level through to constraint-based planning (Turbide, 1998).

The appeal of APS to manufacturers is obvious, because companies can optimize their supply chains to reduce costs, improve product margins, lower inventories, and increase manufacturing throughput. APS necessitates deciding when to build each order, in what operation sequence, and with what machines to meet the required due dates.

In the competitive environment at the twenty-first century, executive management has been looking to purchasing to provide cost reductions, improve supply chain quality, gain across to new sources of technology, improve cycle time, involve suppliers in product and process development, and streamline processes.

Purchasing must perform a number of activities to satisfy the operational requirements of internal customers, which is the traditional role of the purchasing function. More often than not, purchasing supports the needs of operations through the purchase of raw materials, components, subassemblies, repair and maintenance items, and services.

Purchasing may also support the requirements of physical distribution centers responsible for storing and delivering replacement pans or finished products to end customers. Purchasing also supports engineering and technical groups, particularly during new product development.

Today many industries are moving away from vertical integration and relying increasingly on external suppliers. Purchasing must support this movement by providing an uninterrupted flow of high-quality goods and services mat internal customers require. Supporting this Row requires purchasing to (a) Buy items at the right price; (b) At the required specification; (c) In the right quantity and (d) For delivery at me right time.

One of the most important objectives of the purchasing function is the selection, development, and maintenance of supply. This is what strategic supply management is all about. Purchasing must select and manage a supply base capable of providing performance advantages in product cost, quality, technology, delivery, or new product development (Monczka, Trent and Handfield, 2002)

2. Problem definition

Since production in a flexible industrial process is on a massive scale and requires long operating times, it is very important to make a production schedule that meets the due dates. Specific characteristics of a flexible industrial process include small lot size and operations that take a long time. If a customer order exceeds the due date, alternative machines, including outsourcing, should be used for operations related to the job. The makespan should be minimized to keep the due date for each customer order.

The structure of the supply chain in a flexible industrial process is shown in Figure 1. This chain has a four-level (supply, fabrication, assembly, customer) structure.

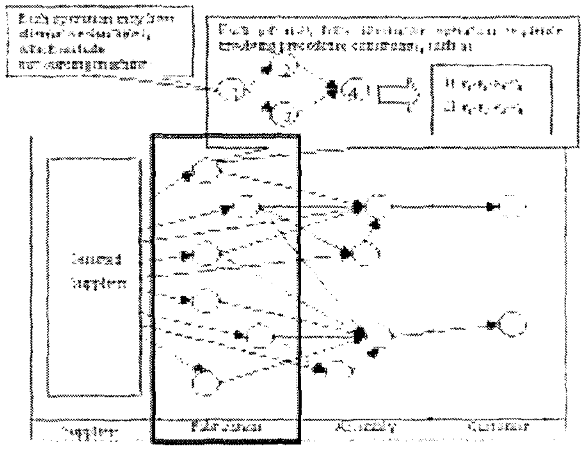

Figure 1. Make-to-order supply chain in a flexible industrial process

At the customer level, there are multiple orders with specific due dates. The product for each order is assembled after the required parts have been fabricated. Assuming that each product is produced in a specific assembly process, a product might need several parts, produced in related jobs at the fabrication level. Each assembly process can begin only after all the fabrication jobs have finished, and each assembly process is interrelated with the other assembly processes. Each job at the fabrication level produces a specific part for a product in an order, and may consist of several operations. At this point, the operations forming a fabrication job may include precedence constraints.

In reality, some of the operations involved in a job do have precedence constraints, and some of the operations required to complete the job are interrelated. Therefore, the operations-sequencing problem can be formulated as the well-known Traveling Salesman Problem (TSP) with precedence constraints. The manufacturing system under study consists of k machines (*1, 2, ..., k*) and n different jobs (*1, 2, ..., n*). All the jobs are loaded and processed continuously as a lot, according to a predetermined technological sequence given in the process plan (Nasr & Elsayed, 1990). Each job requires a number of operations, and each of these operations can be performed on a number of alternative, non-identical machines, which include outsourcing machines. A machine should be selected from among alternates for the operation sequence of each job. For a given production order, which involves a mix of jobs and machines, the operation sequence should be selected to maximize the production efficiency of all the jobs.

In this study, we focus on the fabrication and assembly level, because they are bottlenecks in the process and essential to satisfying the due date. Figure 2 shows a schematic diagram of the MTOSC model, with outsourcing.

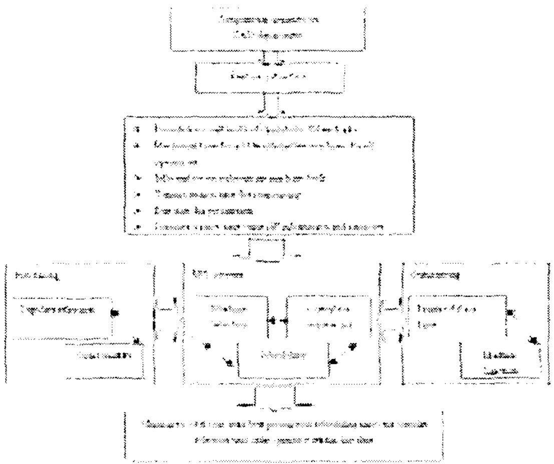

Figure 2. Schematic diagram of the MTOSC model

The MTOSC model in Figure 2 considers five major points: (a) machine selection for each operation; (b) the operation sequence for each job; (c) scheduling; (d) supplier selection and order quantity, and (e) outsourcing. They are integrated and solved simultaneously. Outsourcing is highly related to due date. The model must consider the transportation time of a work-in-process (WIP) part from the main factory to the outsourcing site when a certain operation of the WIP is selected for outsourcing.

This model can (a) determine an optimal schedule with a minimum makespan and holding times of machines, given the due date of each order; (b) select the best machine for each operation; (c) determine the optimal operation sequence of each job; (d) select operations for outsourcing when the machine capacity is not sufficient to keep the due date and (e) obtain a minimized the total cost.

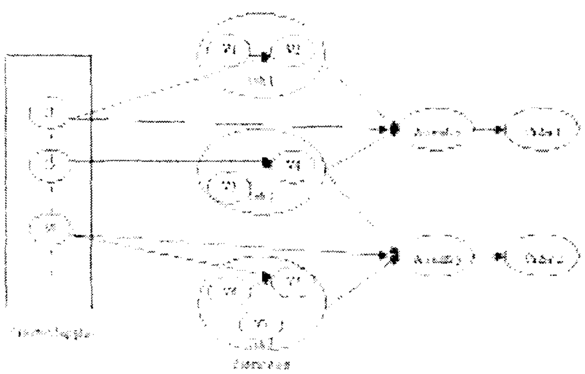

Figure 3. Integrated MTOSC graph for an example instance

Supplier selection process has received considerable attention in the business-management literature. Determining suitable suppliers in the supply chain has become a key strategic consideration. However, the nature of these decisions usually is complex and unstructured. These influence factors can be divided into quantitative and qualitative factors. In this paper, a Multiple-Criteria Supplier Selection (MCSS) model (Jeong and Lee, 2001) is proposed to deal with the supplier selection problems in the supply chain management.

3. Sub-methodologies for MTOSC model

3.1 Fuzzy numbers and linguistic variables

In former paper (Jeong and Lee, 2001), a set scale of linguistic variables was presented to decision-makers for use in describing their evaluations. Hence, the supplier selection problem was considered as a fuzzy MCSS problem. One of the most important issues within these methods is dealing with the ranking of fuzzy numbers to determine the final ranking score of all possible candidates. However, these methods are either focused on a complicated mathematical operations process to rank the fuzzy numbers or unable to provide the total ordering of all alternatives.

In this paper, the vertex method (Chen, 2000) is applied to calculate the distance between two fuzzy numbers. After calculating the final fuzzy rating of each candidate, one can define the closeness and separation values of each candidate. Then, a new ranking index is defined on the basis of the average of closeness and separation values (Chen, 2000). This index is used to determine the score of all possible suppliers for MCSS model. In short, this paper presents a simple and systematic algorithm based on the new ranking index to solve the supplier-selection problem. The proposed method to get the fuzzy scores (Chen 2001) is applied to solve this problem.

3.2 Information sharing

A manufacturing firm invites for bidding contractors capable of realizing parts of the production program. A customizing-type bid (D'Amours, 1999) can be associated with a richer form of business relationship. The supplier establishes its needs (time, capacity) and seeks for a maximum set of alternatives from the contractors. He contractors provide more than just a price. The contractors and the suppliers invest more energy into the relationship. In the make-to-order context, this type of bid describes a set of timing alternatives (sojourn duration), which are distinctively priced. Capacity constraints are imposed on different time-conflicting sets of alternatives in a bid to protect contractors from overload.

3.3 APS methodology with genetic algorithm

In an ordering problem using a GA, a critical issue is developing a representation scheme to represent a feasible solution. It is very difficult to represent a path with precedence constraints in a graph. In order to generate Topological Orders (TOs), the representation scheme must be capable of generating all possible TOs for a given AOV network. In addition, any tour of the solution always corresponds to TOs. Suppose there is one job, which consists of six operations, v_1 through v_6. The chromosome structure can be represented as shown in Figure 4.

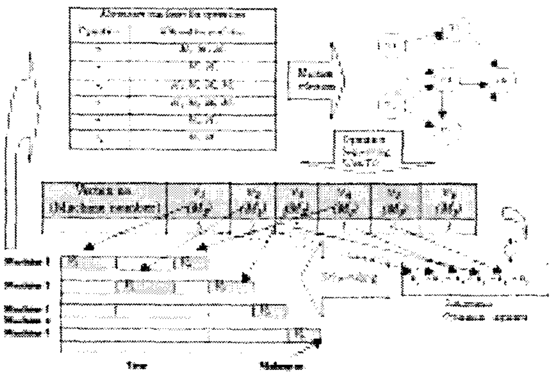

Figure 4. Chromosome representation

In Figure 4, the first row of a chromosome indicates the operations that match a randomly selected machine number to each operation. Each operation randomly selects a machine number from the possible alternative machines. The second row indicates the priority for candidate selection when operations with no incoming edges exist. The value of a gene is generated at random within [1, J] exclusively, where J is the total number of operations. For example, when v_1 and v_2 have no precedence constraints simultaneously, as shown in Figure 4, v_2 is selected for the operation sequence because the priority number of v_2 is 2. After selecting v_2, we can remove v_2 and all edges leading from v_2. Now v_1 and v_5 have no predecessors, and v_1 is selected for the next operation because v_1 has a higher priority than v_5. In the same manner, the operation sequence $v_2 - v_1 - v_4 - v_3 - v_5 - v_6$ is determined for a job and machines M_1-M_2-M_1-M_2-M_3-M_5 are used for each operation sequentially.

4. MTOSC model

To model the integrated APS and purchasing problem, we employed the integrated process planning and scheduling model (Jeong, Lee and moon, 2000) and MSCC model (Jeong and Lee, 2001). The objective function of this MTOSC model is to determine the best production scheduling considering the outsourcing ant to select the best suppliers and the order quantity of each supplier with minimized total cost and satisfying the customer's due date.

Notation:

Q_{ps}: number of units of part p to be ordered to supplier s
z_{ps} : fuzzy score of supplier s for part p
r_p: demand of part p
e : required fuzzy total score
U_{ps} = 1 if supplier s is chosen for part p, 0 otherwise
$cap^{\min}{}_{ps}$: minimal order quantity from supplier s for part p
$cap^{\max}{}_{ps}$: maximal order quantity from supplier s for part p
g: maximum accepted storage cost for all parts
g_p: unit storage cost per unit time for a part p
a_p: demanded arrival time period of part p to the manufacturing firm
W_{psi} = 1 if i_{th} bid of supplier s is chosen for part p, 0 otherwise
p_{psi}: unit production time of i_{th} bid of supplier s for part p
d_{ps}: delivery time from supplier s for part p to the manufacturing firm
f: maximum accepted quality cost for all parts
f^c_{ps} : quality cost of a defect unit of part p purchased from supplier s
f_{ps}: defect percentage of supplier s for part p
c: maximum accepted purchasing cost for all parts
c_{psi}: unit purchasing costs of i_{th} bid of supplier s for part p
n_p: number of suppliers to choose for part p
r : customer order index, $r = 1, 2, 3, \ldots, R$
I : part index for order r, $i = 1, 2, 3, \ldots, I_r$
O : alternative topological order (TO) index for part i, $o = 1, 2, 3, \ldots, O_i$
J : operation index of TO o, $j = 1, 2, 3, \ldots, J_o$
K : machine index containing outsourcing machines, $k = 1, 2, 3, \ldots, K$
R : total number of orders
I_r : total number of parts in order r
O_i : total TO number for part i
J_o : total operations in TO o
K : total number of machines including outsourcing machines
h^c_k : unit holding cost of machine k
H_k : total holding time of machine k
AC_r : assembly cost for customer's order r
DC_r : delivery cost for customer's order r
mat_{riojk} : processing time of operation j in TO o for part i in order r on machine k
TM_{riojk} : completion time of operation j in TO o for part i in order r on machine k
MS_r : makespan of fabrication for customer order r
DT_r : delivery time for customer order r
AT_r : assembly time for customer order r
MP_{rk} : complete process time for machine k in order r
TR_k : one-way transportation time to machine k, located in outsourcing company
D_r : due date for customer order r
L : large positive number

$$X_{riojk} = \begin{cases} 1, & \text{if operation } j \text{ in TO} o \text{ for part } i \text{ in order } r \text{ is performed on machine } k \\ 0, & \text{otherwise} \end{cases}$$

$$R_{riojefgk} = \begin{cases} 1, & \text{if operation } j \text{ in TO} o \text{ for part } i \text{ precedes operation } g \text{ in TO} f \text{ for part } e \text{ in order } r \text{ where operation } j \text{ and } g \text{ are performed on machine } k \\ 0, & \text{otherwise} \end{cases}$$

$$Y_{rio} = \begin{cases} 1, & \text{if process plan } o \text{ for part } i \text{ in order } r \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$$

$$B_k = \begin{cases} 1, & \text{if } k \text{ is an outsourcing machine} \\ 0, & \text{otherwise} \end{cases}$$

$$U_{ps} = \begin{cases} 1, & \text{if supplier } s \text{ is chosen for part } p \\ 0, & \text{otherwise} \end{cases}$$

$$W_{psi} = \begin{cases} 1, & \text{if } i \text{ th bid of supplier } s \text{ is chosen for part } p \\ 0, & \text{otherwise} \end{cases}$$

Model:

$$\begin{aligned} Min\ TC = & \sum_p \sum_s \sum_i c_{psi} W_{psi} Q_{ps} \\ & + \sum_p \sum_s g_p Q_{ps} (a_p - \sum_i (W_{psi} p_{psi} Q_{ps}) - U_{ps} d_{ps}) \\ & + \sum_p \sum_s f^c_{ps} f_{ps} Q_{ps} + \sum_k h^c_k H_k + \sum_r (AC_r + DC_r) \end{aligned} \quad (1)$$

Subject to:

$$\sum_s Q_{ps} = r_p \qquad \forall p \quad (2)$$

$$cap^{\min}{}_{ps} U_{ps} \le Q_{ps} \le cap^{\max}{}_{ps} U_{ps} \qquad \forall p, s \quad (3)$$

$$\sum_s (\sum_i (W_{psi} p_{psi} Q_{ps}) + G_{ps} d_{ps}) \le a_p \qquad \forall p \quad (4)$$

$$\sum_p \sum_s g_p Q_{ps} (a_p - \sum_i (W_{psi} p_{psi} Q_{ps}) - G_{ps} d_{ps}) \le g \quad (5)$$

$$\sum_p \sum_s f^c_{ps} f_{ps} Q_{ps} \le f \quad (6)$$

$$\sum_p \sum_s \sum_i c_{psi} W_{psi} Q_{ps} \le c \quad (7)$$

$$\sum_s U_{ps} \le n_p \qquad \forall p \quad (8)$$

$$\sum_i W_{psi} = 1 \qquad \forall p, s \quad (9)$$

$$\sum_p \sum_s z_{ps} Q_{ps} \ge e \quad (10)$$

$$\begin{aligned} TM_{riojk} \ge \sum_r \sum_i \sum_o \sum_j mat_{riojk} X_{riojk} Y_{rio}, \quad & \forall k \\ \text{where } \sum_{k=1}^{K} X_{riojk} = 1, \quad & \forall r, i, o, j \\ \sum_{o=1}^{O_i} Y_{rio} = 1, \quad & \forall r, i \end{aligned} \quad (11)$$

$$MP_{rk} = TM_{rI_rO_iJ_ok}, \qquad \forall r, k \quad (12)$$

$$\max_{k=1...K}(MP_{rk}) \le D_r - AT_r - DT_r, \qquad \forall r \quad (13)$$

$$TM_{riojk} + L(1 - Y_{rio}) \ge mat_{riojk}, \quad \forall r, i, o, j, k \quad \text{where } j = 1 \quad (14)$$

$$\begin{aligned} & TM_{riojk} - TM_{rio(j-1)m} + TR_k B_k + TR_m B_m + L(1 - Y_{rio}) \ge mat_{riojk}, \quad \forall r, i, o, j, k, m \\ & \text{where } 1 < j \le J_o \text{ and } X_{riojk} = X_{rio(j-1)m} = 1 \end{aligned} \quad (15)$$

$$\begin{aligned} & TM_{riojk} - TM_{refgk} + TR_k B_k + LR_{riojefgk} \ge mat_{riojk} \\ & \text{where } X_{riojk} = X_{refgk} = 1 \text{ and } Y_{rio} = Y_{ref} = 1 \end{aligned} \quad (16)$$

$$\begin{aligned} & TM_{refgk} - TM_{riojk} + TR_k B_k + L(1 - R_{riojefgk}) \ge mat_{refgk} \\ & \text{where } X_{riojk} = X_{refgk} = 1 \text{ and } Y_{rio} = Y_{ref} = 1 \end{aligned} \quad (17)$$

$$TM_{riojk} \ge mat_{riojk}, \quad \forall j \quad \text{where } X_{riojk} = 1 \text{ and } Y_{rio} = 1 \quad (18)$$

$$W_{psi} = 0 \text{ or } 1 \qquad \forall p, s, i \quad (19)$$

$$U_{ps} = 0 \text{ or } 1 \qquad \forall p, s \quad (20)$$

$$X_{riojk} = 0 \text{ or } 1 \qquad \forall r, i, o, j, k \quad (21)$$

$$Y_{rio} = 0 \text{ or } 1 \qquad \forall r, i, o \quad (22)$$

$$R_{riojrfgk} = 0 \text{ or } 1 \qquad \forall r, i, o, j, e, f, g, k \quad (23)$$

$$B_k = 0 \text{ or } 1 \qquad \forall k \quad (24)$$

$$Q_{ps} \ge 0 \quad Q_{ps} = \text{integer} \ \forall p, s \quad (25)$$

In this model, the objective function, equation (1) is to obtain the minimized total cost whose components are purchasing cost, holding cost of machine, holding cost of materials in storage, quality cost and delivery cost. Equation (2) ensures that the total quantity of the provided parts is equal to demand. Equation (3) specifies maximum and minimum capacity of each supplier. Equation (4) ensures that the arrival time of all part p should be equal or less than the demanded arrival time period of part p, which is requested from the manufacturing firm. Equation (5) ensures that the storage cost of parts from all suppliers, which arrived earlier than the demanded arrival time period should be less than maximum accepted storage cost for all parts. Equations (6) and (7) specify the maximum quality cost and the maximum purchasing costs (buy + transportation costs +etc.). Equation (8) ensures the predetermined number of suppliers. Equation (9) ensures that a supplier could not select more than one among the alternative bids. Equation (10) ensures the predetermined limited-fuzzy total score of selected suppliers.

The completion time for operation *j* in TO *o* for part *i* in order *r* on machine *k* (TM_{riojk}) is given by equation (11). The value of TM_{riojk} is obtained when only one TO is selected for each part, and it includes the constraint that only one machine can be selected for each operation. MP_{rk} means the process completion time of machine *k* for order *r* and is defined as equation (12). To satisfy the due date for customer order *r*, equation (13) ensures the due date of customer order *r*.

For operations on the same part and to select the operations to be outsourced, equations (14) and (15) ensure that for a given part *i*, operation *j*-1 processed on machine *m* precedes the next operation (*j*) processed on machine *k*. If *k* is an outsourcing machine, $B_k = 1$ and operation *j* will be selected for outsourcing. Equation (15) requires that the completion times of two operations (such as *j*-1 and *j*) for a part should have a greater difference than the machining time for operation *j*.

For every pair of operations that use machine *k* in TO *j* for part *i* and in TO *f* for part *e*, equations (16) and (17) ensure that a machine cannot be scheduled to process more than one part at the same time and that two different operations cannot be processed simultaneously on the same machine. Equation (18) ensures that the completion time of any operation must at least exceed its processing time. Equation (19)-(25) ensures IP constraints.

5. Conclusions

Although many studies have examined supply chain models, it is still an issue of concern. In the first level, it appears that a fuzzy method may be a useful sub-tool for solving the problem of supplier selection in a supply-chain system. In general, supplier-selection problems adhere to uncertain and imprecise data; therefore, fuzzy-set theory is adequate to get the evaluated score of each supplier for supplier selection problem.

In the second level, we have applied MTOSC model for APS and purchasing (supplier selection and order quantity). A mathematical model proposes the final solution by considering the quantitative and qualitative criteria and supplier and buyer bid constraints in order to obtain the impact of information sharing. In the experiment, considering a type of bid: customizing is used to show how the level of information can affect supplier decisions. The results show that better price-time performance is achieved as high levels of information on price and capacity are shared by the contractors with the manufacturing firm.

Also in manufacturing area, the traditional method, which is limited to non-sequential operations, does not address the availability of alternative machines or operation sequences with precedence constraints. Although outsourcing is a facet of production, it is rarely considered in traditional planning and scheduling models.

To solve the proposed model, a GA-based approach was developed. The approach is a very flexible method that is capable of dealing with huge and complicated problems, as shown in the experiments. The results of the experiments show that the MTOSC model can obtain a reasonable solution with outsourcing and efficient purchasing through a GA-based approach. The solution converges within reasonable iterations because the GA performs a multi-directional search by maintaining a population of potential solutions. The proposed approach has the strength to obtain a best solution efficiently from the feasible solution area, although the solution may not be optimal.

In the future study, an efficient solution-generating method for complex MTO supply chain system may be needed to adjust to a changing manufacturing environment.

References

Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment, *Fuzzy Sets and Systems*, 114, 1-9.

Chen, C. T. (2000). Handling fuzzy MCDM problems using a new ranking index, *Proc. 8th Bellman Continuum International Workshop on Intelligent Systems Resolutions*, Taiwan, 181-185.

Chen, C. T. (2001). Supplier selection method for supply chain system, *Proc. 16th International Conference Production Research*, Czech.

Chung, D., Lee, K., Shin, K., & Park, J. (2000). An algorithm for job shop scheduling problem with due date constraints considering operation subcontract, *Proc. 15th ICPR International Conference*, Bangkok.

D'Amours, S., Montreuil, B., Lefrancois, P., & Soumis, F. (1999). Networked manufacturing: The impact of information sharing, *Int. J. Production Economics*, *58*, 63-79.

Jeong, C. S., Lee, Y. H. (2001), A Multi-Criteria Supplier Selection (MCSS) Model for Supply Chain Management, *Proc. Fall conference of Korean Institute of Ind. Eng.*, Myeong-JI Uni., Young-in.

Jeong, C. S., Lee, Y. H., & Moon, C. (2000), A model for integration of process planning and scheduling with outsourcing in manufacturing supply chain, *IE Interfaces, 13, 3*, 512-520.

Kolisch, R. (2000). Integrated assembly and fabrication for make-to-order production, *Int. J.*

Prod. Econ., 65, 289-306.

Monczka, R., Trent, R., Handfield, R. (2002). *Purchasing and supply chain management*, South-Western, a division of Thomson learning, Cincinnati.

Nasr, N., & Elsayed, A. (1990). Job shop scheduling with alternative machines, *Int. J. of Production Research, 28*, 1595-1609.

Turbide, D. (1998). Advanced planning and scheduling (APS) systems, *January / February 1998 issue of Midrange ERP magazine*.