Determining Decoupling Points in a Supply Chain Networks using NSGA II Algorithm

Maryam Karimi and S. H. Yakhchali

Abstract— **The decoupling point (DP) is gaining attention as a significant factor in the design and management of supply chains. The DP divides the part of the supply chain oriented towards customer orders from the part which is based on forecast planning and it can be stated that DP separates production process from lean production system to agile system so we can use the advantages of both production systems. Position of the decoupling point is a key factor that influences the design and management of a supply chain. In this study, we describe decoupling point's determination as a multi objective decision making (MODM) problem, and our objectives are minimization of production cost and production delivery time and maximization of customer satisfaction. We use NSGA II for determining Pareto optimal solution, to extract some solution concept. Finally a numerical example is applied to validate applicability and feasibility of the proposed model and performance of the developed algorithm.**

Keywords— **Decoupling Points, Lean and Agile production system, MTO and MTS strategy, MODM, NSGA II Meta Heuristic Algorithm.**

I. Introduction

The decoupling point is gaining attention as a significant factor in the design and management of supply chains. Selection of decoupling points is a strategic decision since it determines customer lead times and inventory investment. Decoupling point and its location is a key factor that influences the design and management of a supply chain; some products are produced to order (i.e. customized to particular customer needs) whereas others are produced to stock (standard products) (Olhager, 2012).

In section 1 the literature and importance of the DP was stated. In section 2 we explore multi-objective problem and NSGA II algorithm. Section 3 is our proposed model and experimental results are shown in section 4. Finally in section 5 the conclusions and future research are presented.

II. Multi-objective decision making

In a multi-objective decision problem, there are multi objectives and we want to reach their desired values. Although this problem is regarded as optimization problems, in such problem we have some new concepts that are different from classical operation research problems. One of the most important issues in MODM is the fact that it is usually impossible to reach optimal value of all objectives in one solution. In other words, there might be conflict between objectives that cause reaching to one goal leads to stay away from other goals. A MODM problem can be stated as follow:

$$\text{minimize } y=f(x)=(f_1(x),f_2(x),...,f_q(x))$$

$$\textit{where } x \in R^p, \textit{and } y \in R^q$$

The most common solution concept in MODM problem is Pareto optimal solutions. To describe this concept we must first consider non-domination solution. A vector $\vec{x}_1$ dominates another vector $\vec{x}_2$, if the following two conditions are satisfied (Rahimi and Vahed, 2009):

1) $\vec{x}_1$ is at least as good as $\vec{x}_2$ regarding all objectives, and;
2) $\vec{x}_1$ is strictly better than $\vec{x}_2$ for at least one objective.

All such non-dominated vectors are called Pareto optimal. In Figure 2, Pareto optimal solutions formed a frontier that is called Pareto efficient and is placed on the bottom left of feasible region (Rahimi and Vahed, 2009). The Pareto optimal points are points that there isn't any other point with better objective value than them. The reminded question here is which Pareto optimal solution is chosen as final solution. We say this decision depends on decision makers' desirability. So in this concept we choose solution through Pareto solution regarding utility function of decision makers. Many approaches and techniques address this problem, such as goal programing,

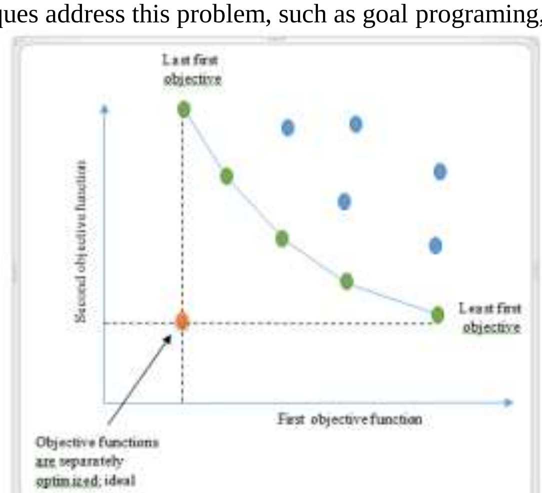

Fig.2 Pareto Optimal Solution and Pareto Frontier(based on Rahimi-Vahed, 2009)

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weighting approach, preference and non-preference techniques, priori methods, posteriori methods and Interactive methods (Hwang, 1979 and Miettinen, 2008).

III. Proposed Model

The decoupling points in a supply chain network are the points that separate production process from lean production system to agile system. Lean production is based on MTS strategy. In MTS, productions are held in warehouse until the receipt of an order comes and after that, productions are delivered and triggers are generated from a post-station to pre-station. These triggers information are production pulses and a station answers that pulse with available production when it receives such pulse, and production reduction in that station denotes to start reproduction. As we can see, in this situation the product that delivered to customer is based on standardized characteristics so the customer's desires aren't exactly met but the delivery time is at its minimum level. In Figure 3, this mechanism is shown (Sun, 2008).

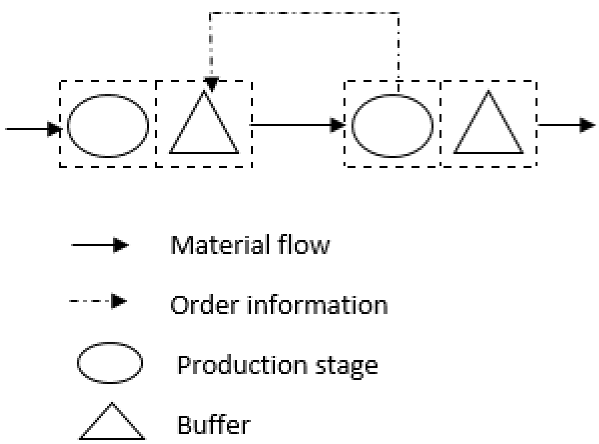

Fig. 3 MTS system (sun, 2008))

On the other hand, agile production is based on MTO strategy and customers demand is perfectly based on customer's favorite requirement. So in such system when a station receives an order, it starts to produce that customized order. In this case, customer satisfaction and delivery time is at its maximum level and the production cost also increases for the large adjustment in design of product and facilities. In Figure 4, MTO mechanism is shown (Sun, 2008):

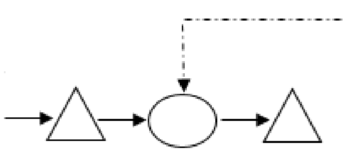

Fig. 4 MTO system (sun, 2008)

According to above description, each strategy has its advantages and disadvantages. So in order to benefit both, we decompose a supply network into two sections, an upstream operations and downstream operations. Regarding to decoupling point, upstream operations are placed before decoupling point and downstream operations are placed after decoupling point. Upstream operations work as MTS and downstream operations work as MTO. In literature MTS and MTO also refer to push and pull strategy respectively.

According to aforementioned description, in order to determine decoupling point, we must take in to account three aspect of problem, in other words we must follow three main objectives. These objectives are: minimizing cost of production, minimizing production delivery time and maximizing customer satisfaction. So we have a multi-objective problem and in this paper we use NSGA II algorithm to extract solution concepts i.e. Pareto optimal solutions.

As stated in section 1, by determining the DP we can benefit both lean and agile production systems. A lean supply chain should be applied upstream the CODP, while an agile supply chain would be more suitable for downstream operations. See figure 5. In this paper we use the supply chain network suggested in Sun (2008) that prepare a good framework to model supply chain by regarding precedence relationship between consequence operations in a supply chain. This network representation also enables us to compute the delivery time of finished product to customer. In this case we have multiple decoupling points that are formed based on the line that separates the nodes in such network on two parts. In Figure 6 (Sun, 2008), the nodes represent product, as Pi's are raw material, A1:A3 are works in process and A4 is finished material. The arcs that connect nodes represent activities required to transform the nodes to each other. These activities are production process, assembly process and so on. Each arrow contains a time and the critical path from root to the leaf that shows the delivery time of product corresponds to that leaf. As we described above, the MTS operations cause no delivery time so the time of corresponding arrows for all such nodes are set zero. As in this case our decision variables are considering operations as MTS or MTO, we only use cost structures that are particular for one of these strategies or have significant meaning regarding MTS or MTO and neglect common structures. For MTS operations, production is based on prediction. In this case we use standard features, so in production processes including such operation, we have almost no adjustment. However in this case we have holding cost of product. This cost is particular for MTS, so this is one of our cost structures. Another significant cost is setup cost which in MTO is relatively large, because we must pay this cost for each product. In MTS this cost is related to the extent of batch used for production, so in MTS this cost is prorated. For MTO we have extra cost of customization that can be considered as special design of MTO operations demanded by customers. In this paper we assume that the demand has fixed rate that we show it as D and the production rate is also constant namely P. We also has a supply network that formed based on bill of material (BOM) so we can easily calculate all product demands.

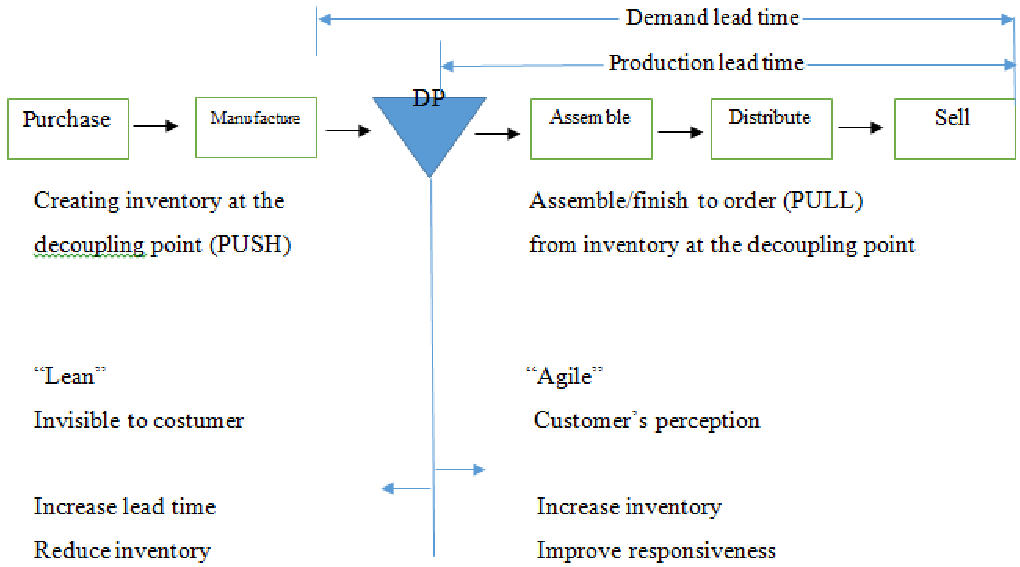

Fig. 5 Separating agile and lean operations by DP

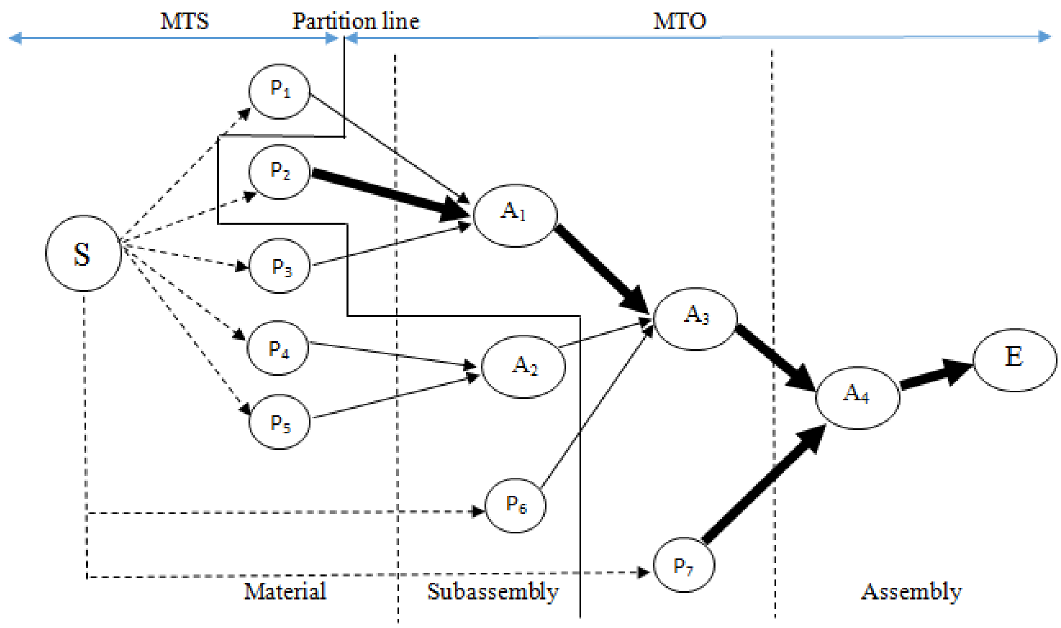

Fig. 6 supply chain network (sun, 2008)

We assume that we have BOM matrix that element (i, j) shows the number of product j that is needed to produce one product i. So if we use variable Di to describe total demand of product i, we have the following relationship between demands:

$$D_i = \sum_{j \in product, j \neq i} BOM(i, j) \quad (1)$$

So if the demand of final product is known, following BOM and relation (1) we can easily get demands of all intermediate products.

Using following notation we can formulate cost and satisfaction level at MTS and MTO production:

D_i : Demand for product i

S_i: Set up cost for each production activation of product i

H_i : Holding cost for each unit of product i in a year

u_i : Demand rate of product i

p_i : Production rate

CS_i : Cost for customization of product i per each unit

cf_i : Standard satisfaction factor of product i

cs_i : Customized satisfaction factor of product i

Here the most important decision is whether an operation or the product obtained as a result of that operation is MTS based or MTO based. So we define variable O_i as follow:

$$O_i = \begin{cases} 1 & \text{if product } i \text{ is MTO based} \\ 0 & \text{else} \end{cases}$$

Our proposed model to determine decoupling points is as follow:

$$\min(TC, T, -CS) \tag{2}$$

$s.t:$

$$T_{path} = \sum_{i \in path} T_i . O_i \tag{3}$$

$$T \geq T_{path} \quad \text{for all paths} \tag{4}$$

$$O_i \geq O_j \quad \text{for all } i \text{ and } j \text{ such that } j \in \text{all path rooted from } i \tag{5}$$

$$TC = \sum_{i \in product} ((S_i D_i + COS_i D_i).O_i + (1-O_i).\sqrt{2 D_i S_i H_i (1-\frac{u_i}{p_i})}) \tag{6}$$

$$CS = \sum_{i \in product} (O_i .cf_i + (1-O_i).sf_i) \tag{7}$$

$$O_i = \{0,1\} \tag{8}$$

Equation (2) describes objective functions that in this case are minimization of total cost and delivery time and maximization of customer satisfaction. We can find total time of each path from root to finished product by constraint (3). So if we define delivery time as T we use constraint (4) to utilize critical path method to determine delivery time. As stated constraint (4) determines delivery time of final product. As previously mentioned each operation has a time and when that operation is MTO based, we consider its time in delivery time. To do that we must first define a constraint that explain if an activity is considered as MTO, then all operations after that is also considered MTO, and this fact is described as constraint (5). So regarding MTS and MTO the total cost is calculated as constraint (6). Equation (7) determines customer satisfaction of final product. This satisfaction is sum of satisfaction of each part of the product. MTO parts have satisfaction value equal to cf_i and MTS part has satisfaction value equal to sf_i and it is obvious that cf_i is greater than sf_i.

In this model we assume that each product based on MTS strategy, isn't allowed to have any shortage otherwise we have no longer the assumption that MTS delivery time is equal zero. As we know this model is an Economic Production Quantity (EPQ), for simplicity we assume setup time is zero, so we compute the total cost including holding cost and setup cost as equation 9:

$$TC_i^* = \sqrt{2 D_i S_i H_i (1-\frac{u_i}{p_i})} \tag{9}$$

On the other hand if an operation is a MTO one, the set up cost of that operation is S_iD_i, because in this case, we pay setup cost for all demands. Furthermore in this strategy we have customization cost for all orders. If we assume the cost of customization for product *i* be CS_i we have the total cost for MTO product as follow:

$$TC_i = S_i D_i + CS_i D_i \tag{10}$$

Now to evaluate performance of proposed model we simulate numerical example and by applying NSGA II we attempt to extract Pareto optimal solutions. To use NSGA II we must decode original problem to appropriate one for implementing mutation and crossover operation in NSGA II algorithm. In this case our decision variable is binary variable O_i which is defined for each operation. So we decode this problem by using a binary string of length m (m is number of operations). We can generate random solution by assigning 0 and 1 randomly to each gen in string and apply mutation and crossover. The only constraint that can be violated by such operation is constraint (5). So after random generation, mutation and crossover we need to modify solutions to satisfy this constraint. To do so, in coding this problem when a variable is assigned value 1 i.e. is considered as MTO operation, all variable on the trees that was rooted from that operation modified to have value equal to 1. The NSGA II algorithm used in this study has been coded in visual basic language programing.

IV. Conclusion and Future Research Directions

The intense growth in products variety and competitions between firms, leads firms to produce more customized product according to customers' requirements. However this will increase productions cost and products delivery time to customers as well. Therefore in some situations we need to balance customer requirements with cost and capabilities of production in supply network. Decoupling point determination is a common practice that is used to address these issues. It Separates a supply chain in two parts and enables firms to use advantages of both lean and agile production system. The first part is composed of MTS operations that use standard features and refers to lean production systems and the second part is composed of MTO operations that adjust production to meet specific customer orders. Therefore, efficient determination of decoupling point has found great interest in production concepts. In this paper we presented a new model to address this problem as a MODM problem. The proposed model here has minimizing production cost, minimizing delivery time and maximizing customer satisfaction as its objectives and considering operations as MTO or MTS as binary decision variables.

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