Negotiation Based Collaborative Planning In Two-tier Supply Chain

Yuan Chao, Hao Wen Lin, Tomohiro Murata

***Abstract*—This paper focuses on a negotiation based collaborative planning process for order pattern determination of multi-period planning in a two-tier supply chain scenario. The aim is to study how negotiation based planning processes would be used to refine locally preferred ordering patterns, which would consequently affect the overall performance of the supply chain in terms of costs and service level. Minimal information exchanges in the form of mathematical models are suggested to represent the local preferences and are used to support the negotiation processes.**

***Keywords*—Negotiation, collaborative planning, supply chain.**

I. INTRODUCTION

Production planning is a management process that aims to determine the best usage of manufacturing resources in order to satisfy the overall production request over a certain period. In general, production request is derived from both actual customer orders (Make-to-order) and the anticipated sales opportunities as forecasted by local management based on historical data and consumer trends (Make-to-Inventory) [(1)]. Production requests and the actual market demands however, often suffer costly inconsistencies due to forecasting errors. In the current era, a manufacturing system does not exist as a single body but rather a collection of entities, and that each entity performs a unique set of operations to add values to a product and brings the product a step closer to the end consumers. These manufacturing entities differ from specialized functional workshops within a manufacturer, to groups of manufacturing partners that form tightly inter-dependent supply chains. Between these entities, coordinated planning is critical to ensure that the production request at each entity is determined as synergistically as possible for each planning period, so that unnecessary manufacturing resource wastage and excessive inventory carrying costs would be effectively avoided.

According to Stadtler [(2)], coordinated planning can be performed on operations such as production, storage, and the distribution of goods. This type of processes is a central element of Supply Chain Management (SCM). Coordinated planning can be categorized into centralized and collaborative approaches. The centralized planning approach implements a hierarchical technique where all relevant information must be collated by a top management entity, and that medium-to-long term decisions are made here about the overall production requirements for the entire manufacturing system. The top level decisions are cascaded down to a series of short-term objectives at every local entities of the manufacturing system. The centralized approach is not suitable for all types of SCM problems mainly due to the following three issues. Firstly, the collation of all relevant information from all entities is difficult to achieve due to the natural boundaries existed between the considering entities. This is especially true when business confidentiality is an important issue between the members of a supply chain [(3)]. Secondly, objectives that are derived from top level decision may not be decent or not preferred by the local entities, and there is a lack of empowerment to dictate local entities to perform such operations. Thirdly, the centralized planning problem would be highly complicated due to a large number of parameters, variables, and conflicting constraints existed between different entities. The problem would be difficult to model and analyze in detail within a reasonable time. Collaborative planning is another approach which can be applied to both downstream and upstream planning modes, as well as suitable for long-term, medium-term and short-term planning periods [(4)]. Using the collaborative planning approach, each partner can freely analyze and determine optimal local planning goals, and then exchange only the relevant information that would be just enough to support negotiation processes that aim to refine local decisions in order to achieve best possible overall plan for the entire manufacturing system [(5)]. Without information sharing each partner only possesses knowledge of its own operations and that local demands are often inaccurately forecasted. Suppliers forecasted demand at the end of each production cycles based on their best guesses of their buyers' needs with respect to their previous order quantities. Without proper communication, all partners in the supply chain determine their local optimal plans using only the local information. This will typically result in poor performance with unexpected high cost, large inventory or shortage and amplified demand swings as described by the "bullwhip effect" [(6)]. In order to improve the performance of a supply chain, the planning process of each partner in the supply chain should be linked and synchronized with each other. A coordination scheme which synchronizes operations and improves total cost of multi-buyer and single supplier with multiple productions is described in Dudek and Stadtler [(7)].

This study aims to use mathematical models to represent

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the preferred multi-period order pattern for every member of a two tier supply chain scenario that consists of a single buyer and multi-suppliers. Further, a negotiation scheme is applied on the models in order to determine a consensus order pattern throughout the supply chain, which simultaneously optimizes the overall order fulfillment ratio and operational costs. The problem overview is presented in Section 2 of this paper. The mathematical model and the negotiation scheme used for solving the problem are defined in Section 3. An example is given in Section 4 to demonstrate the application of the approach introduced in this paper. Finally, conclusion and discussion on future work are included in Section 5.

II. Problem Overview

A. *Supply Chain Model*

This paper focuses on model building and negotiation formulation for collaborative planning processes in a two-tier supply chain scenario, where there is a single buyer and multiple suppliers. As depicted in Fig. 1, each supplier has a set of unique production processes, which can be requested to produce their corresponding product families $P_{s,j}$. The production requests of $P_{s,j}$ are triggered by the buyer as specific $P_{s,j}$ are required as input components to produce P_j at the buyer's end. All production processes are performed on some specific resources, and that each type of resources has its unique performance parameters as well as capability and capacity constraints.

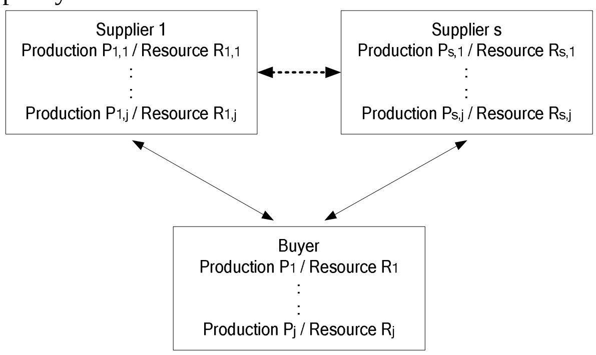

Fig. 1. The two tier supply chain system

Based on the demand of their local products, the buyer can request orders from all of the suppliers to fulfill the part requirements of their local production commitments. It is undesirable for the buyer to source their input components from a single supplier as each supplier has different production capacity, delivery lead-time, and pricing on their products. The buyer must determine the most preferred ordering patterns from all of the suppliers that would eventually best support its internal performances. Apart from this quantitative aspect, there are qualitative benefits on sourcing from multiple suppliers. Firstly, it is a desired tactical approach for the buyer to balance its orders between the suppliers in order to minimize the impacts of manufacturing risks, such as machine breakdown and workforce shortage, which could impair the performance of any specific supplier. Furthermore, maintaining multiple suppliers could offer a decent capacity buffer to cope with the end buyer's demand fluctuations. Finally in the presence of multiple suppliers, a competitive environment can be created between the suppliers, which would result in improved product and service qualities for the buyer. Besides the competition, there can also be cooperation between suppliers. In this paper, the cooperative environment is defined as the collaborative planning between suppliers as in the second case.

In practice, each supplier would generally serve multiple buyers, and that the overall demands would sometimes exceed a supplier's production capacity. Under such scenario, the supplier needs to determine the production capacity that can be allocated to each buyer at every planning period depends on the historical demand from buyer and the buyer's importance level. Further, each supplier would set its unique minimum ordering quantity in order to ensure a reasonable return on every customer order. Buyer will ask for this information at the beginning of each planning horizon and this will be used by the buyer to determine its initially preferred purchase quantity for each supplier in every planning period considered.

B. *Negotiation process*

The negotiation process presented in this paper has three main stages. Firstly, the buyer asks for the information on minimum ordering quantity and ordering capacity for every period of the planning horizon that has been suggested by each supplier. The buyer then generates its local planning for order quantity based on these kinds of information and his own demand.. Secondly, suppliers receive the order from the buyer and verify it against their existing production requests and capacities. Each supplier then determines whether the ordering quantity from the buyer is out of his maximum production capacity for this buyer or not. If the supplier can't satisfy the ordering quantity by himself at this step, he can also make order to some other suppliers which will work as outsourcing. Then its desired supply quantity to the buyer is generated.. Finally, the buyer receives the proposed supply quantity from each supplier and decides if the order for each supplier needs to be refined. If refinement is needed, the process is iterated until a best possible consensuses solution is obtained. In this process, the buyer will have more power on choosing which suppliers would be requested to produce its supplies. The mathematical models used to represent the preferences at each stages of the negotiation process are introduced in the following section.

III. Model Formulation and Negotiation Process

This section is dedicated to define the mathematical models, and to introduce the negotiation process that would form the overall approach to solve the problem presented in Section II. The mathematical models are used to represent the local preferences of the buyer and suppliers, and they also form the focal discussion point for the evaluation negotiation of the process.

Notation

Sets

S supplier set

T planning period

Data

ch holding cost of buyer

ch_s holding cost of supplier s

cf fixed setup cost of buyer

cf_s fixed setup cost of supplier s

cp_s price for buying product from supplier s

$cp\_s_{s,s1}$ selling price for each supplier s from supplier $s1$

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cs shortage cost of product of buyer

cs_s shortage cost of product of supplier s

cap capacity of buyer

cap_s capacity of supplier s

D_t Buyer's forecast demand over period

r unit requirement of supplied product

I starting inventory of product

IS starting inventory of supplied products

$xo\_max_{s,t}$ maximum order quantity

$xo\_min_{s,t}$ minimum order quantity

$lost_s$ products that can't be produced by supplier s according to the order at the end of the period

$over_s$ the more products that can be produced by supplier s according to the order

Variable

c total cost

c_s cost of each supplier s

i_t inventory of product

y_t setup variable

x_j output of product

is_t inventory of supplied product

$xs_{s,t}$ order from buyer

sh_t shortage quantity

$x\_supply_{s,t}$ supplied quantity from supplier s during period

x_order order quantity from buyer

$xr_{s,s1,t}$ ordering quantity to supplier *s1* by supplier *s* in planning period *t*.

$xl_{s,s1,t}$ supplying quantity from supplier *s* to supplier *s1* in period *t*

$xr\_s_{s,s1,t}$ supplying quantity from supplier *s1* to supplier *s* in period *t*

$xl\_order_{s,s1,t}$ order supplier *s* gets from supplier *s1* in period *t*.

A. Negotiation process

The negotiation process is triggered by the buyer's will to purchase supplies from suppliers. The buyer will first perform its local planning and generate a preferred order pattern according to the model explain in sub-section III-B. After the suppliers get the order from buyer and other suppliers, they will check the order and generate their preferred supply to buyer and other suppliers if necessary according to his minimum ordering quantity and maximum production capacity and transfer the result back to buyer or to other suppliers by using the model in sub-section III-C. The last thing for the cycle is for the buyer to regenerate his preferred order based on the supply quantity replied from the suppliers, which are generated by the model defined in sub-section III-D. The negotiation cycle is terminated when the deviation between ordering quantity and supplies reduces to a certain level. This terminating condition can be interpreted as the buyer and the suppliers are agreeing on a particular ordering pattern that both satisfies the final demand and that each member is satisfied with their respecting operational costs. An overview of the whole negotiation process is depicted in Fig. 2.

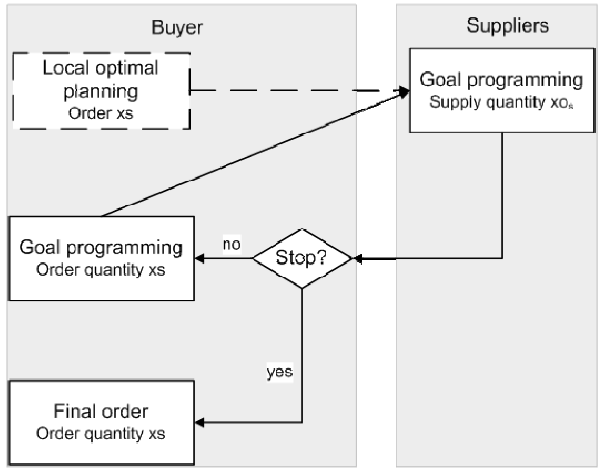

Fig. 2. Negotiation process

B. Buyer's local planning model

$$\min \quad c$$

$$s.t.$$

$$c=\sum_{t\in T}\left(ch\cdot i_t+cf\cdot y_t\right)+\sum_{s\in S}\left(cp_s\cdot\sum_{t\in T}xs_{s,t}\right) \quad (1)$$

$$i_{t-1}+x_t=D_t+i_t \quad (2)$$

$$i_0=I \quad (3)$$

$$i_t,x_t\geq 0 \quad (4)$$

$$x_t\leq cap\cdot y_t \quad (5)$$

$$y\in\{0.1\} \quad (6)$$

$$xs_{s,t}\geq xo\_min_{s,t} \quad (7)$$

$$\sum_{s\in S}xs_{s,t}=r\cdot x_t \quad (8)$$

Equation (1) calculates the total cost for the production of the buyer's local planning. Constraint (2) considers the flow balance between demand, inventory and output. Constraint (5) ensures that the capacity restrictions would satisfy the production setup requirements. Constraint (7) forces the ordering quantity to be larger than the minimum ordering quantity, which is requested by suppliers. While satisfying the output demand *x* and inventory level *I* for the products produced by the buyer, the model determines the order request quantity *xs* from each supplier using constraint (8). The objective of the model is to minimize the total local order fulfillment costs.

C. Buyer's goal programming model

$$\min \quad c+\sum_{t\in T}\left(d1_t^{+}+d1_t^{-}\right)+\sum_{s\in S}\left(d_s^{+}+d_s^{-}\right)$$

$$s.t. \quad (3)-(7)$$

$$c=\sum_{t\in T}\Big(ch\cdot\left(i_t+is_t\right)+cf\cdot y_t+ cs\cdot sh_t\Big)+\sum_{s\in S}\left(cp_s\cdot\sum_{t\in T}xs_{s,t}\right) \quad (9)$$

$$r\cdot i_{t-1}+r\cdot x_t+d1_t^{+}=r\cdot D_t+d1_{t-1}^{+}+r\cdot i_t \quad (10)$$

$$is_{t-1}+\sum_{s\in S}xs_{s,t}=r\cdot x_t+is_t \quad (11)$$

$$is_0=IS \quad (12)$$

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$$is_t, xs_{s,t} \geq 0 \tag{13}$$

$$\sum_{s \in S} xs_{s,t} + d1_t^+ + d1_t^- = \sum_{s \in S} x\_supply_{s,t} + d1_{t-1}^+ + d1_{t+1}^- \tag{14}$$

$$\sum_{t \in T} xs_{s,t} + d_s^+ + d_s^- = \sum_{t \in T} x\_supply_{s,t} + d_{s-1}^+ + d_{s+1}^- \tag{15}$$

$$xs_{s,t} \leq xo\_max_{s,t} \tag{16}$$

$$if \left(\sum_{s \in S} lost_s < \sum_{s \in S} over_s \right) \quad d1_1^- = \sum_{s \in S} \left(over_s - lost_s \right) \tag{17}$$

$$if \left(\sum_{s \in S} lost_s \geq \sum_{s \in S} over_s \right) \quad d1_1^- = 0 \tag{18}$$

$$if \left(\sum_{s \in S} xs_{s,t} + is_{t-1} > r \cdot D_t \right) \quad sh_t = d1_0^+ = r \cdot D_t - \sum_{s \in S} xs_{s,t} - is_{t-1} \tag{19}$$

$$if \left(\sum_{s \in S} xs_{s,t} + is_{t-1} \leq r \cdot D_t \right) \quad sh_t = d1_0^+ = 0 \tag{20}$$

$$deviation = \left| \sum_{t \in T} r \cdot D_t - \sum_{t \in T} \sum_{s \in S} xs_{s,t} \right| \tag{21}$$

The new function $d_s^{+/-}$ is the modification between suppliers and the $d1_t^{+/-}$ defines the modification between planning periods.

Constraint (9) shows the total cost of buyer's goal programming which includes inventory holding cost, setup cost, shortage cost and purchasing cost. Constraint (10) and (11) balance the supplied products from the suppliers, requirement of the products and the existing inventory. Constraint (14) suggests the buyer to make little changes on the supply quantity to achieve an improved overall order fulfillment cost for the system. The refined order quantity is replied back to the suppliers as the new order quantity in the next negotiation cycle. In this model, the ordering quantity can be adjusted between each supplier, and also between each planning period. These features are realized by Constraints (14) and (15).

Constraint (16) defined that the ordering quantity should not be larger than the maximum ordering quantity that is considered for the current iteration.

If all of the orders in the planning period have been satisfied by the suppliers, there won't be any backorder quantity. If the supply is suggested to be more than the desired ordering quantity, then backorder will not be considered in the following planning iteration. Otherwise, the backordered parts should be added back into the adjustment at the beginning of the next planning period. This is shown as constraints (17), (18), (19) and (20). As the deviation between the buyer's demand and supply is changed during the iteration, it will be considered as the deviation (21) should be less than the one from last iteration.

D. Supplier's goal programming model

$$\min \quad c_s + \sum_{t \in T} \left(d1_{s,t}^+ + d1_{s,t}^- \right)$$

$$c_s = \sum_{t \in T} \left(ch_s \cdot i_{s,t} + cf_s \cdot y_{s,t} + cs_s \cdot d1_{s,t}^+ \right) + \sum_{s1 \in s} cp\_s_{s,s1} \bullet \sum_{t \in T} xr_{s,s1,t} \tag{22}$$

$$i_{s,t-1} + x_{s,t} + \sum_{s1 \in S} xr_{s,s1,t} = xo_{s,t} + i_{s,t} + \sum_{s1 \in S} xl_{s,s1,t} \tag{23}$$

$$i_{s,0} = I_s \tag{24}$$

$$i_{s,t}, x_{s,t} \geq 0 \tag{25}$$

$$x_{s,t} \leq cap_{s,t} \cdot (1 + 0.2) * y_{s,t} \tag{26}$$

$$y_{s,t} \in \{0,1\} \tag{27}$$

$$xo_{s,t} + \sum_{s1 \in S} xr_{s,s1,t} + \sum_{s1 \in S} xl_{s,s1,t} + d1_{s,t}^+ + d1_{s,t}^- = xs_{s,t} + \sum_{s1 \in S} xl\_order_{s,s1,t} + d1_{s,t-1}^+ + d1_{s,t+1}^- \tag{28}$$

$$xr_{s,s1,t} + d2_{s,s1,t}^+ + d2_{s,s1,t}^- = xr\_s_{s,s1,t} + d2_{s,s1,t-1}^+ + d2_{s,s1,t+1}^- \tag{29}$$

$$xo_{s,t} \geq cap_{s,t} \tag{30}$$

$$d1_{s,0}^+, d1_{s,1}^- = 0 \tag{31}$$

New variable $d1_{s,t}^{+/-}$ captures the modification from supplier *s* to the order and supply quantities between planning period *t*.

Constraint (22) is the total cost of each supplier's goal programming which includes inventory holding cost, setup cost and shortage cost, and the last part in this constraint is the purchasing cost for ordering from other suppliers. Constraint (23) defines the flow balance between inventories, outputs, products supplied from other suppliers, orders from the buyer, and orders from other suppliers. Constraint (28) allows the supplier to make a little change on the order as the final supply quantity to the buyer and other suppliers. Each supplier has to consider with his maximum production capacity that can be allocated to the buyer. In the model, the maximum production capacity is defined as 20 percent larger than the minimum ordering quantity. This scenario is represented using constraints (26) and (30).

The new function $d2_{s,s1,t}^{+/-}$ stands for the modification of release from supplier *s1* between planning period *t* which is made by supplier *s*.

The order between suppliers also is defined as if there is no order in period *t* from other supplier, one supplier can't modify any release to other suppliers. Moreover, if there is order from others in planning period *t*, one can't make order back to this supplier in this period.

In this planning process, the supplier will consider its local production capacity with total cost, and decides how many buyers to supply to.

IV. Example

In this section, a simple example is used to illustrate the strength of the approach presented in Section 3. The example considers there are a single buyer and a total of three

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suppliers. Two cases are used in this section for comparing the performance of the negotiation process. In case one, negotiation process is built only between buyer and supplier While the negotiation process is built between suppliers as well in the other case. The values of parameters used in this computation test are shown in the following tables. Table 1 shows the production capacity of each supplier. The capacity will be static during the planning horizon.

Table 2 is the selling price obtained from each supplier, which is static but their values are different from each other. The supplier with largest production capacity has the lowest selling price while the smaller one has the highest selling price. The selling price is also use in the second case in this paper for each supplier.

The forecast demand of buyer over 4 periods is shown in Table 3.

Table 4 and Table 5 summarize the results of the buyer's final ordering quantity in each planning period from each supplier in case 1 and case 2. Fig. 3 depicts the adjustment of the total ordering quantity and the operation cost of buyer during the negotiation process. It is demonstrated by the result that the negotiation improves both of the objectives that are considered in the model.

Table 1. Production capacity ($cap_{s,t}$)

Activity	Period 1	Period 2	Period 3	Period 4
Supplier 1	140	140	140	140
Supplier 2	80	80	80	80
Supplier 3	180	180	180	180

Table 2. Price from each supplier (cp_s)

Activity	Selling price
Supplier 1	**40**
Supplier 2	**60**
Supplier 3	**20**

Table 3. Forecast demand of buyer (D_t)

Activity	Period 1	Period 2	Period 3	Period 4
Buyer	403	441	476	576

During the negotiation process, the fulfillment ratio of the buyer increases, and the total operation costs reduces. As the negotiation process iterates, the buyer's ordering quantity becomes better satisfied by the suppliers. Hence the shortage, which inherently affects the overall operation costs, will be reduced. Using the model, the fulfillment ratio of the buyer has been increased from 91.98% to 100.16% in case 1 and from 95.73 to 100.05% in case 2 and that the overall operation costs are also significantly reduced.

Fig. 3 also shows that in case 2 the fulfill ratio increase quickly while the starting level of fulfill ratio is higher than that in case 1, after that, the fulfill ratio in case 2 has some small adjustment and can be stopped whenever buyer consider. However, because of the demand between suppliers, the supplying level from each supplier will not be very hard, and it becomes a factor which will impact the supply to buyer.

Table 4. Final ordering quantity (Case1)

Activity	Period 1	Period 2	Period 3	Period 4
Supplier_1	163	168	168	168
Supplier_2	80	96	96	96
Supplier_3	183	221	244	216

Table 5. Final ordering quantity (Case2)

Activity	Period 1	Period 2	Period 3	Period 4
Supplier_1	176.5	176.5	163.5	165.5
Supplier_2	86	80	80	80
Supplier_3	219	220	225	225

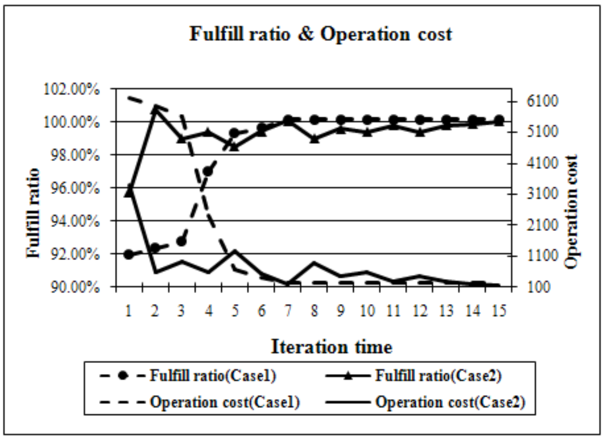

Fig. 3. Buyer's fulfill ratio and operation cost

Fig. 4 shows the change of inventory and shortage level of each planning period along the number of negotiation process iteration, where the color bars stand for the inventory and the grey bars are the shortage. At iteration 1, the buyer's order cannot be satisfied at the end of the planning horizon and a large number of shortage exists. As the negotiation process goes by, the shortage is reduced. Since the ordering quantity in the last planning period is the largest, the production capacity within the period cannot fulfill the demand, and that necessary inventory must be carried over from previous periods. After several iterations, the ordering quantity is satisfied at the end of planning horizon and adjustment is taken to reduce the unnecessary inventory.

V. Conclusion

In this paper we have presented our study on a negotiation based collaborative planning process for determining the optimal ordering pattern between two suppliers and on buyer in a multiple planning period scenario. The result shows the strength of the approach in reducing the overall operational cost of the two tier supply chain system, and it improves the overall performance of all the members in the system. In the proposed approach, it is demonstrated that through the usage of mathematical models, local preferences of each partners in the system can be concisely represented and is suitable for supporting the negotiation process.

The study on the collaborative problem presented here is still at an early stage, and the model introduced in this paper is very simple. There are many performance variables, inter-relationships, constraints, and conflicting goals not yet considered in the current model. Further research and experimental work are needed to refine the model and make it practical for solving real industrial problems. These studies would include the consideration of logistics cost, the balance of the inventory cost and logistics cost, multiple product types, more complex production inter-relationships between the buyer anti its suppliers, and performance analysis on the mathematical models and the negotiation process.

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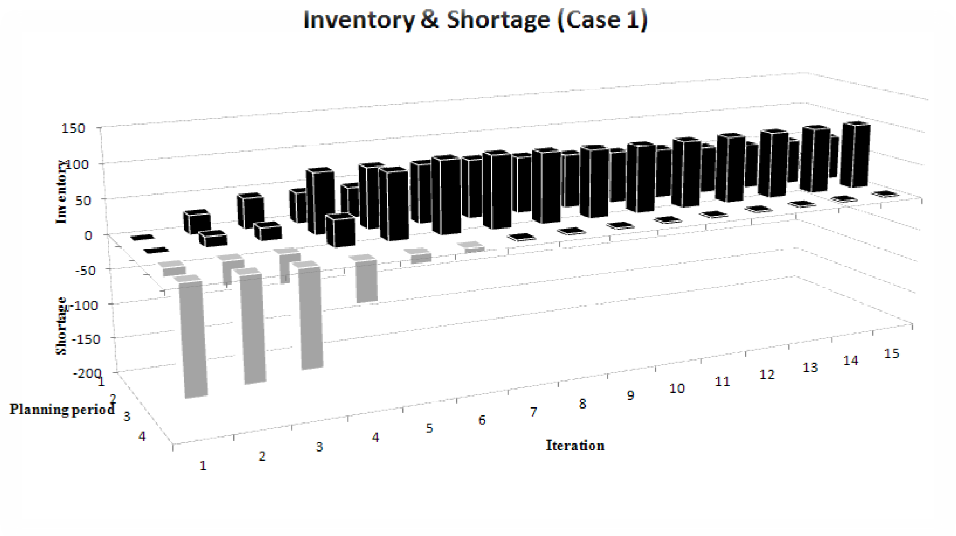
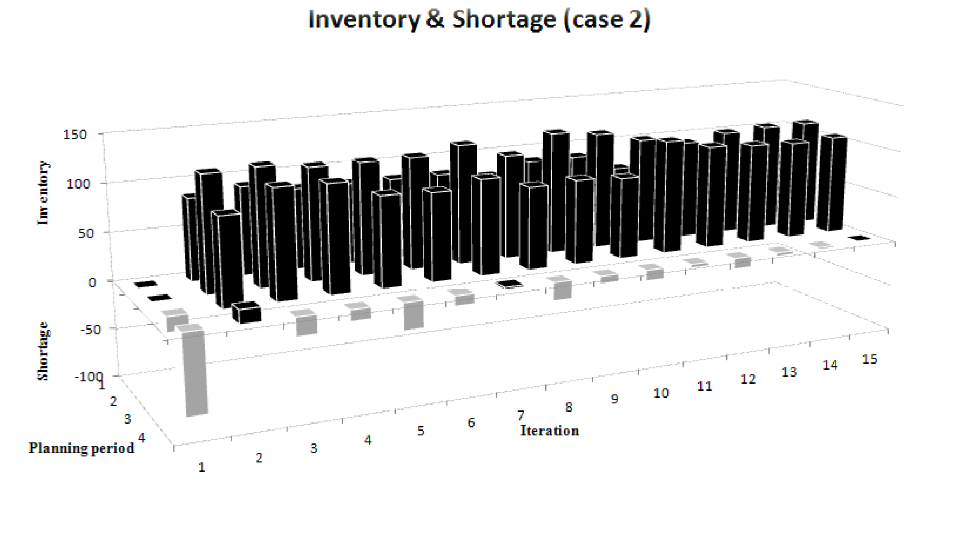


(a) Case 1



(b) Case 2

Fig. 4. Inventory and shortage

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