Decentralized Production Distribution Planning in a Supply Chain with Out-Sourced Logistics

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Abstract

Outsourcing is a method where the firm want to focus on their core competencies, and sub-contract the other activities like distribution to a firm which is having expertise in that area. In majority of the supply chains that are present today, the logistics function is outsourced to an expert in the logistics area. In these supply chains, there is a need for cooperation between the logistics service provider and manufacturer for smooth functioning of these activities and to reduce the overall costs. A practical difficulty in outsourced supply chain models is lack of trust between the channel partners. For example, when the logistics function is outsourced, the logistics service provider and manufacturer do not like to share complete information about their domain with other partner. This is because, they think that by doing so, they will lose grip in their domain. But they share only, partial information with the other. To address these types of problems, models known as Decentralized supply chain models are developed. In this work, a Centralized Production-Inventory-Distribution model has been proposed for a supply chain with three echelons. Also, a decentralized production-distribution model was proposed with the same supply chain with three levels. The supply chain considered in this work consists of two manufacturing plants, two distribution centres, and four customer zones.

1. INTRODUCTION

Accurate and timely information about market demand is important for efficient supply chain management. The demand at downstream node must be made available
to the upstream node for reducing the safety stocks at upstream nodes. Without the accurate information about demand at downstream node, the upstream node managers keeps large amount of safety stocks, and this safety stocks amplifies as one moves upwards across the supply chain. This trend of demand signal amplification as the demand signal moves upwards across the supply chain is called ‘Bullwhip effect’. The bullwhip effect causes excess stocks to be maintained at upstream nodes and hence leads to excessive inventory costs. To eliminate the bullwhip effect, the upstream and downstream channel partners must collaboratively plan, forecast, and replenish the stocks (C.P.F.R). The channel members must build long-term relations and trust with each other and must share the information about their domain with the others. The channel members must have a long-term vision and should share the benefits of information sharing, so that the channel partners continue to share accurate information. To achieve this channel partners should make contracts with the others regarding the costs and benefits to be shared.

But there are some practical difficulties of accurate information sharing between channel partners. The channel partners do not like to share complete information about their domain with the others. This is because, they feel, that by doing so, they will lose grip in their domain and also they feel that the shared information could reach their rivals. Hence they share only partial information. This trend is observed in information sharing with an out-sourced company where the out-sourced company may be a producer or a transporter. In this type of supply chain, there are multiple decision makers with different objectives, for example the objective of a transporter may be to minimize the transportation costs and the objective of a producer may be to minimize the production related costs. In this type of supply chains each decision maker is modelled as an agent and all the agents share partial information about their domain with the other partners. Also, there is a coordination mechanism to coordinate all the agents to obtain the final optimal plans for the supply chain. This type of supply chains is called Decentralized supply chain.

In Centralized supply chain models there is complete information sharing between channel partners. That is in this type of supply chain, there is a single decision maker. For example when the transporting vehicles are owned by the plant owners, the centralized supply chain models are appropriate.

In this work, a case study has been taken up for a domestic pump supply chain located in south India. In this supply chain the distribution function is out-sourced to a third party. Hence the Decentralized supply chain model is found to be appropriate. This supply chain has three levels (echelons) plants, distribution centres, customer zones. The supply chain in the case study has two plants, two distribution centres, and 4 customer zones. There are 8 products manufactured by the plant and distributed to customer zones through distribution centres. The time period considered for the case study is twelve months (April to March). The demand of the products at the customer zones has been obtained from the plant owners.

Both the Decentralized and Centralized supply chain models were presented and implemented in this work to show the benefits of centralization. Two modelling
environments were considered in this Work viz., GAMS win 64 24.9.1 and MATLAB R 2015b. In GAMS modelling environment. Two types of solvers were used viz., CPLEX and LINDO. In MATLAB environment also, two types of solvers are used, namely, linprog and intlinprog solvers. Again for each decentralized production-distribution planning model, two variants are used, namely Distributor leader and producer follower case and Producer leader and distributor follower case depending on who initiates the information sharing process.

2. LITERATURE REVIEW

Accurate and up-to-date information about market demand should be made available to all channel partners (manufacturers, suppliers, distributors) for seamless integration of the supply chain. Information sharing has many advantages – decreasing the cost, shorter response time to market changes, better integration between the partners, better delivery. There is a positive correlation between the level of information sharing and supply chain performance (Mansour Rached et al., 2015). The performance of the supply chain depends on what information is shared, when and with whom it is shared, and how it is shared. Inaccurate and delayed information sharing has dysfunctional effects on the supply chain performance as the information passes from one level of supply chain to the other (Juliang Zhang et al., 2013). Generally, the channel partners are reluctant to share information, as they feel that it would lead to loss of their power, and also feel that the shared information could reach their rivals. Because of this reason, the members share minimal information. Many researchers have emphasized the importance of information sharing in a supply chain (Suhong Li and Binshan Lin, 2006, Mansour Rached et al., 2015, Yeu-Shiang-Huang et al., 2016, Juliang Zhang et al., 2013, Fei-Ye et al., 2013, Erin.M.Mitchell et al., 2015). Mutual trusts and shared vision of the top management are important for accurate information sharing (Suhong Li and Binshan Lin, 2006). The supply chain partners must build long-term relationships and trust with each other (Zainah Abdullah et al., 2014). The typical information that is shared includes inventory levels, demand at downstream level, and supply at upstream level, costs, and capacities, possible risks like supply disruptions at plants, major break-downs etc (Yeu-Shiang-Huang et al., 2016). By using this shared information, the supply chain costs can be reduced and profits can be increased. The channel members must be allotted proper share in the increased profits, because these are the result of their information sharing (Huiping Ding et al., 2011). Many researchers have investigated this topic of profit-sharing/revenue sharing (Huiping Ding et al., 2011, Hamed vafa Arani et al., 2016). These profits must be distributed to the channel members so that the supply chain partners are motivated and cooperate with each other and continue to share important and accurate information.

Co-ordination of information sharing:-

It is well known that there are two notorious effects of a supply chain. Double marginalization effect and Bullwhip effect. Double marginalization effect means that
the total profit of a supply chain under decentralized decision is less than that under the centralized decision. Bullwhip effect means that the demand order variation amplifies when the information passes from downstream to upstream. Bullwhip effect causes inefficient use of production and distribution resources, high production and inventory costs. To minimize these effects, the supply chain members are advised to collaboratively plan their production and other resources by sharing accurate information about their domain with other members.

Collaborative planning, forecasting, and replenishment (C.P.F.R):-
Collaborative planning, forecasting, and replenishment (C.P.F.R) is a system where the retailers, distributors, manufacturers and suppliers will collaboratively plan their production, inventory, and distribution and supply quantities by sharing accurate information about their domain with upstream and downstream members. Without collaborative planning, a member of supply chain do not know the demand, and supply at downstream and upstream members respectively, and hence cannot prepare good plans. With C.P.F.R the supply chain cost is reduced, inventories are optimized, and supply chain can respond quickly to market changes, and also it can deliver the right quantity of goods at right time.

Out-Sourcing :-
Outsourcing is mainly employed especially by start-ups and SMEs (Small and Medium Enterprises) which have a financial constraint to limit their financial budget and focus on core competencies (Sushma Kumari et al, 2015). When a firm outsources its activities to a third party, it makes contracts with them, to supply raw materials and components, transport products, store the materials in warehouses, etc. Also when a firm out-source its activities, it makes contracts to coordinate with the out-sourced parties to improve the performance of the supply chain. These contracts include revenue sharing contracts, cost sharing contracts, buy-back contracts, output penalty contracts etc (Xiaoyan Xu et al, 2015, Benrong Zheng et al, 2017, Maosen Zhou et al, 2017, Tatyana Chernonog and Tal Avinadav, 2017, Benyong Hu and Yi Feng, 2017).

Several types of coordination contracts have been found in the literature. The basic contracts include revenue-sharing, buy-back, and quantity flexibility contracts. Recently option contracts have been introduced as contracts in supply chains. Revenue-sharing is a contract mechanism where the supplier sells at a low wholesale prices and gets a fraction of the revenue of the buyer (Hamed Vafa Arani et al, 2016). In buy-back contracts, the supplier will buy the unsold goods of the buyer at a reduced price at the end of the season (Linh and Hong, 2009). This problem is like a newspaper boy problem, where the news paper boy will sell the unsold papers on the next day at a small price. In option contract mechanism, the buyer gets the right to own an asset after a maturity date. It acts like a financial instrument (Wang, 2015). There are two types of option mechanisms, viz., call option and put option.
In real-world supply chains, the channel members (buyers and sellers) have conflicts about the incentive that they receive as a result of information-sharing. These give rise to two models, known as cooperative game models (complete information sharing) and non-cooperative game models (asymmetric information sharing). (Wang and Chen, 2013, Zhao et al, 2013). In Asymmetric supply chain one of the players (manufacturer or retailers) assumes the leader role and the other player assumes the follower role. The leader initiates the information sharing and the follower follows the leader. Also, information asymmetry can result because of inaccurate information regarding inventory level. In many industries, the inventory levels which are on-record are different from the true inventory levels that are present on the shop floor. These inventory inaccuracies can be eliminated by using modern technology by installing RFID systems for inventory tracking.

Supply chain risk:-
Supply chain risks come in many forms – supplier uncertainty, unreliable suppliers, and uncertain demand information, and untimely supply and demand information, disruptions and so on. Supplier relationship, supplier selection, and supply contract are generally used to hedge against the supply risks. Customer relationship, buy-back, customer contract are used to hedge against demand uncertainty. Lean manufacturing, lean supply chains, just-in-time, six sigma, and TQM are used to hedge against risks caused by disruptions.

Risk sharing:-
To improve the supply chain performance in the long-run, the supply chain members should share the risks in their domain with other members, so that they prepare plans to face these risks. The various uncertain parameters which cause risks in a supply chain are demand, supply, costs, capacities, prices of finished goods, prices of raw materials, production/processing times, transportation times etc.

Supply chain disruptions:-
Supply chain disruptions include the occurrence of events such as breakdown of critical equipment, excess absenteeism, strikes; etc leads to loss of production, delayed delivery, uncertain supply, and loss of reputation and so on. The risks that are likely to be caused by these disruptions must be shared with the upstream and downstream members, so that they can prepare plans to face these risks. Several companies are using lean manufacturing, lean supply chains, just-in-time, six sigma, TQM, and other tools to quantify these risks and roll out plans to face those risks.

Uncertainty and supply chain risk:-
To be more realistic, the supply chains must be modelled with uncertainty. The
various uncertain parameters in a supply chain are demand, supply, costs, capacities, prices of finished goods, prices of raw materials, production/processing times, transportation times etc.

Supply chain network design under uncertainty:-
Supply chain network design is a strategic decision which has long-term effects. These decisions cannot be changed, without huge loss. Supply chain network design includes decisions related to number and location of manufacturing and distribution facilities, type of facilities, capacities of facilities, and selection of suppliers. Hence, to design supply chain networks to last for a long time, uncertainties of supply chains must be considered. The uncertain parameters include demand, supply, capacities, prices of finished goods, prices of raw materials, production/processing times, transportation times, and so on.

3. METHODOLOGY:-

3.1. NOMENCLATURE –

List of symbols and parameters

Dem_{ict} The demand for item i at customer c in time t.

hcapa_{idt} The inventory holding capacity for item i at d/c (distribution center) d in time t.

capa^{PA}_{pt} The total available manufacturing capacity for plant p in time t.

rcapa_{ipt} The requested(desired) manufacturing quantity for item i at plant p in time t.

util^{P}_{ip} The manufacturing capacity utilization rate per unit of item i in plant p.

util^{I}_{ip} The inventory capacity utilization rate per unit of item i in plant p.

mcapa^{P}_{pt} The total available manufacturing capacity for plant p in time t.

icapa^{P}_{pt} The total available inventory capacity for plant p in time t.

Cost^{1}_{ict} The unit lateness cost for item i at customer c in time t.

Cost^{2}_{idt} The unit earliness cost for item i at d/c d in time t.

Cost^{3}_{ipdt} The unit distribution cost for item i from plant p to d/c d in time t.

Cost^{4}_{idct} The unit distribution cost for item i from d/c d to customer c in time t.

Cost^{5}_{ipt} The unit manufacturing cost for item i at plant p in time t.

Cost^{6}_{ipt} The unit inventory carrying cost for item i at plant p in time t.
**Cost**$_{ipt}$  The unit unfulfilled penalty cost against the requested quantity from the DA for item i at plant p in time t. (set to a very big number)

**Decision Variables**

- **late$_{ict}$**  The lateness amount for item i at customer c in time t.
- **earli$_{idt}$**  The earliness amount for item i at d/c d in time t.
- **transpd$_{ipdt}$**  The distribution amount for item i from plant p to d/c d in time t.
- **transdc$_{idct}$**  The distribution amount for item i from d/c d to customer c in time t.
- **reqcapa$_{ipt}$**  The required(desired) production amount for product p at factory f in period t.
- **y$_{ipt}$**  The production amount for item i at plant p in time t.
- **inv$_{ipt}$**  The inventory amount for item i at plant p in time t.
- **q$_{ipt}$**  The unfulfilled amount against the requested amount for item i at plant p in time t.

### 3.2. DECENTRALIZED PRODUCTION DISTRIBUTION PLANNING MODEL:-

#### 3.2.1. Proposed Model:-

The proposed model consists of three echelons (levels), namely plants, Distribution centers (warehouses), and customer zones. The problem is modeled by two software agents (two linear programs), one each for distribution and production.

#### 3.2.1.1. Distribution Agent (DA):-

The Distribution Agent (DA) will minimize the distribution related costs which include, costs like lateness costs, earliness costs, transportation costs from plant to warehouses, and transportation costs from warehouses to customer zones. Lateness costs are incurred when a product is delivered after its’ due date. The lateness costs reflect the reputation and goodwill lost by the firm by delivering a product after its due date. Earliness costs are incurred when a product is delivered before its’ due date. The objective of distribution agent is to minimize the sum of lateness cost, earliness cost, transportation costs from plants to distribution centers and from distribution centers to customers for all the items in all time periods. The distribution agent will minimize his objective function subject to constraints such as meeting the demand at
customer zones, inventory balance constraints and limit on maximum earliness quantities. That is, the Distribution agent (DA) is a linear program.

The objective function of D.A. (1) minimizes the sum of lateness cost, earliness cost, and transportation cost from plant to d/c and from d/c to customer. Eq.(2) and (3) are material balance constraints. Eq.(4) limits the maximum allowable earliness. Eq (5) is used to find the desired production quantity to be communicated to P.A. eq (6) is used to limit the maximum desired production quantity. Eq (7) are non-negativity restrictions on variables

\[
\min \sum_{i,c,t} \text{Cost}_{1, i,c,t}^{1} \text{late}_{ict} + \sum_{i,d,t} \text{Cost}_{2, i,d,t}^{2} \text{earli}_{idt} + \\
\sum_{ipdt} \text{Cost}_{3, ipdt}^{3} \text{transp}_{ipdt} + \sum \text{Cost}_{idct}^{4} \text{transd}_{idct}
\]

Subject to

\[
\sum_{d \in D(c)} \text{transd}_{idct} = \text{Dem}_{ict} - \text{late}_{ict} \quad \forall \, i,c,t
\]

\[
eali_{i,d,t-1} + \sum_{p \in P(d)} \text{transp}_{ipdt} = \text{earli}_{idt} + \sum_{c \in C(d)} \text{transd}_{idct} \quad \forall \, i,d,t
\]

\[
earli_{idt} \leq \text{hcapa}_{idt} \quad \forall \, i,d,t
\]

\[
\sum_{d \in P(p)} \text{transp}_{ipdt} = \text{reqcapa}_{ipt} \quad \forall \, i,p,t
\]

\[
\sum_{i} \text{reqcapa}_{ipt} \leq \text{capa}_{pt}^{PA} \quad \forall \, p,t
\]

\[
\text{late}_{ict} \geq 0, \text{earli}_{i,d,t} \geq 0, \text{transp}_{ipdt} \geq 0, \text{transd}_{idct} \geq 0,
\]

\[
\text{reqcapa}_{ipt} \geq 0, \quad \forall \, i,p,d,c,t
\]

3.2.1.2. Production Agent (PA) :- The production Agent (PA) will minimize the production related expenses which include producion costs, inventory holding costs and unfulfilled costs. The objective of Production agent (PA) is to minimize the sum of production related costs mentioned above. The PA will minimize the production related costs subject to constraints on inventory balance constraints, production and inventory capacity constraints. The unfulfilled costs are incurred when a demand requirement from DA is not fulfilled by the PA. These costs are fixed at a high value so as to prefer production to shortage situation.

The objective function of P.A (8) minimizes the sum of production cost, inventory cost, and unfulfilled cost. Eq (9) is material balance constraint. Eq,(10) indicates that maximum production quantity is limited by plant capacity. Eq (11) indicates that maximum inventory quantity is limited by storage capacity. Eq. (12) is non-negativity restrictions on variables.
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\[
\text{Min } \sum_{i,p,t} \left( \text{Cost}^5_{ipt} y_{ipt} + \text{Cost}^6_{ipt} \text{inv}_{ipt} + \text{Cost}^7_{ipt} q_{ipt} \right)
\]

Subject to

\[
\text{inv}_{i,p,t-1} + y_{ipt} = rcapa_{ipt} + \text{inv}_{ipt} - q_{ipt} \quad \forall i,p,t
\]

\[
\sum_i \text{util}^p_{ip} y_{ipt} \leq mcapa^f_{pt} \quad \forall p,t
\]

\[
\sum_i \text{util}^i_{ip} \text{inv}_{ipt} \leq icapa^i_{pt} \quad \forall p,t
\]

\[
y_{ipt} \geq 0, \text{inv}_{ipt} \geq 0, q_{ipt} \geq 0 . \quad \forall i,p,t
\]

3.2.1.3 Algorithm for modification of the Capacity of PA, \( \text{capa}^{PA}_{pt} :\)

\[
\min_{m=1,2,...,k} \left( \sum_i \text{reqcapa}^m_{ipt} - \sum_i q^m_{ipt} \right) \rightarrow (k + 1^{th}) \text{capa}^{PA}_{pt} \quad \text{when}
\]

\[
\exists q^m_{ipt} \geq 0 , i \in [1,2,...,k-1] (k)^{th} \text{capa}^{PA}_{pt} \rightarrow (k + 1^{th}) \text{capa}^{PA}_{pt} \quad \text{Otherwise (13)}
\]

Where \( k \) is current iteration number and \( \text{reqcapa}^m_{pft} , \text{rcapa}^i_{pft}, b^i_{pft} \) indicate the resultant values of \( m^{th} \) iteration respectively.

Initially, the distribution agent will minimize the distribution related costs subject to its own constraints. During this process the DA will not consider the plant capacity constraints. The DA will communicate to PA, the desired production quantity. The desired production quantity for a given item at a given plant in a given time period is calculated as the sum of transportation quantities of that item in that period from all distribution centers to that plant. This desired production quantity is communicated by the DA to PA. Now the PA will use this desired production quantity and manufacturing and inventory capacity constraints to minimize production related costs. That is the PA will determine the possible production quantity. Using this possible production quantity, the plant capacity is modified according to an algorithm (eq.13). This Modified Plant Capacity is communicated to the DA and the DA will minimize the distribution related costs with the addition of the new constraint that the distribution quantity of all items between plant and distribution centre in a given period will not exceed the Modified Plant Capacity. The variables that are exchanged between the DA and PA are shown by bold letters. This iterative exchange of information between the DA and PA is continued until there is no planning gap. That is the desired production quantity is not greater than the possible production quantity.
3.2.1.4. Algorithm:

*Iter = 1;*

Do until there is no reduction in total cost (while loop)

**Step 1:** Solve DA L.P.P to minimize DA Cost

**Step 2:** obtain desired production quantity from DA Plan (rcapa)

**Step 3:** communicate desired production quantity (rcapa) to PA.

**Step 4:** solve PA L.P.P to minimize PA Cost.

**Step 5:** compute total cost (DA Cost + PA Cost)

**Step 6:** obtain possible production quantity from PA plan.

- **Step 7:** check whether desired production quantity is less than or equal to possible production quantity If yes stop the algorithm. If no go to step 8

- **Step 8:** modify the capacity of PA according to eq. 13.

- **Step 9:** communicate modified capaPA to the DA L.P.P.

- **Step 10** Add the modified capaPA constraint (eq. 6) to the DA L.P.P.

*Iter = iter + 1;*

End while

3.3. CENTRALIZED PRODUCTION DISTRIBUTION PLANNING MODEL:-

\[
\text{Min} \sum_{i,c,t} \text{Cost}_1^{i,c,t} \text{late}_{i,c,t} + \sum_{i,d,t} \text{Cost}_2^{i,d,t} \text{earli}_{i,d,t} + \sum_{i,p,t} \text{Cost}_3^{i,p,t} \text{transpd}_{i,p,t} + \sum_{i,d,c,t} \text{Cost}_4^{i,d,c,t} \text{transdc}_{i,d,c,t} + \sum_{i,p,t} \text{Cost}_5^{i,p,t} y_{i,p,t} + \text{Cost}_6^{i,p,t} \text{inv}_{i,p,t} + \text{Cost}_7^{i,p,t} q_{i,p,t} \\
\]

(14)

Subject to

\[
\sum_{d \in D(c)} \text{transdc}_{i,d,c,t} = \text{Dem}_{i,c,t} \quad \forall i,c,t
\]

(15)

\[
eali_{i,d,t-1} + \sum_{p \in P(d)} \text{transpd}_{i,p,d,t} = \text{earli}_{i,d,t} + \sum_{c \in C(d)} \text{transdc}_{i,d,c,t} \quad \forall i,d,t
\]

(16)

\[
\text{earli}_{i,d,t} \leq h \text{capa}^e_{i,d,t} \quad \forall i,d,t
\]

(17)

\[
\sum_{d \in P(p)} \text{transpd}_{i,p,d,t} = \text{reqcapa}_{i,p,t} \quad \forall i,p,t
\]

(18)

\[
\sum_i \text{reqcapa}_{i,p,t} \leq \text{capa}_{p,t}^{PA} \quad \forall p,t
\]

(19)
Equation (14) minimizes the sum of lateness cost, earliness cost, distribution cost from plant to distribution centre and distribution cost from distribution centre to customer zones. Equation (15) that the demand at a customer zone is the sum of transportation quantity from distribution centre to customer zone and the lateness cost at the customer zone. Eq. (16) is a material balance constraint at the distribution centre. Eq (17) limits the maximum earliness to earliness capacity. Eq (18) is used to find out the required capacity at the plant which is given as the sum of the transportation quantities from that plant to all distribution centres. Eq (19) is used to constrain the required capacity at the plant to capacity of the production agent. Eq (20) is a material balance constraint for the plant. Eq (21) limits the maximum production quantity at the plant to that plant capacity. Eq (22) limits the maximum inventory at the plant to that plant’s inventory holding capacity. Eq (23) are non-negativity constraints which limits the variables to be greater than or equal to zero.

4. CASE STUDY

A case study has been conducted in this work on a domestic pump manufacturing supply chain located in south India. This supply chain consists of two manufacturing plants, 2 distribution centres, and 4 customer zones. Each of the manufacturing plant manufactures 8 products. The data on demand and capacities and costs for all the products has been obtained from reliable sources. The data has been collected for 12 months (April to March). This data has been used in this work to develop optimum production, inventory distribution plans for the total time horizon. Two types of models have been used in this work. Centralized and decentralized production distribution planning models. These two models have been implemented in GAMS win 64.24.9.1 and MATLAB R 2015b.

5. IMPLEMENTATION

The proposed Centralized and decentralized production distribution planning models have been implemented in GAMS win 64.24.9.1 and MATLAB R 2015b. Same data which is collected by conducting the case study is used for the two modelling environments. In GAMS implementation CPLEX and LINDO solvers have been used.
IN MATLAB implementation linprog and intlinprog of MATLAB’s built-in solvers have been used. From the experience, it is found that it is easy to model in GAMS environment than in MATLAB environment.

The case study in this work involves a domestic pump supply chain consisting of 2 plants, 2 distribution centres, 4 customer zones. Each plant can manufacture 8 types of products. The data on demand, costs and capacities of all the 8 products at each plant and customer zone has been obtained from the plant owners for 12 months (April to March) period.

6. RESULTS

The complete results for production, inventory and distribution plans for all the products for all the time periods will occupy around 7 to 8 pages (The total number of variables are around 2000 for this work) . Hence it is proposed to provide in this paper only summarized results and graphs. The algorithm shown in 4.2.1.4 has been run for 15 iterations in GAMS and MATLAB using the solvers CPLEX and LINDO solvers in GAMS environment and MATLAB’s built-in solvers linprog and intlinprog in MATLAB environment. The best values for Distribution Agent Cost (DAC) and Production Agent Cost (PAC) and Total Cost (TC) for decentralized planning and centralized planning are shown in the Tables 1 to 6 and graphs (Figures 1 to 4) below. Also, the benefit from centralization is shown in the Tables 1 to 6. The graphs showing the distribution agent cost (DAC) and production agent cost (PAC) and the total cost (TC) in iteration 1 and 15 for the decentralized planning and the total cost for centralized planning using CPLEX and LINDO solvers has been shown in Figures 1 to 4.

<table>
<thead>
<tr>
<th>Iteration</th>
<th>PAC (Rs)</th>
<th>DAC (Rs)</th>
<th>TC(Rs)</th>
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<tbody>
<tr>
<td>Iteration 1</td>
<td>3.145666E+08</td>
<td>4.130725E+07</td>
<td>3.344283E+08</td>
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<tr>
<td>Iteration 15</td>
<td>1.334845E+08</td>
<td>6.355310E+07</td>
<td>1.970164E+08</td>
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<tr>
<td>Centralized SCM</td>
<td>950000</td>
<td>1.315692E+08</td>
<td>1.325193E+08</td>
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<tr>
<td>Benefit from Centralization = Rs. 0.644971E+08</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Iteration</th>
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<th>DAC(Rs)</th>
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<tr>
<td>Benefit from Centralization = Rs. 0.668815E+08</td>
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Fig. 1: Distributor leader – Solver CPLEX

Fig. 2: Manufacturer leader – Solver CPLEX
Fig. 3: Distributor leader – Solver LINDO

Fig. 4: Manufacturer leader – Solver LINDO

Table 3: Modeling Environment – GAMS - Manufacturer Leader – CPLEX_LP_MIP

<table>
<thead>
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<th>Solver</th>
<th>PAC (Rs)</th>
<th>DAC (Rs)</th>
<th>TC (Rs)</th>
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<td>1.421673E+08</td>
</tr>
<tr>
<td>Centralized SCM</td>
<td>950000</td>
<td>1.315692E+08</td>
<td>1.325193E+08</td>
</tr>
<tr>
<td>Benefit from Centralization = Rs. 0.09648E+08</td>
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<td></td>
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</tbody>
</table>
### Table 4: Modeling Environment – GAMS - Manufacturer Leader – LINDO_ LP_MIP Solver

<table>
<thead>
<tr>
<th>Iteration</th>
<th>PAC(Rs)</th>
<th>DAC(Rs)</th>
<th>TC(Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iteration 1</td>
<td>3.12316E+08</td>
<td>1.986230E+07</td>
<td>3.539058E+08</td>
</tr>
<tr>
<td>Iteration 15</td>
<td>1.006180E+08</td>
<td>6.189945E+07</td>
<td>1.627705E+08</td>
</tr>
<tr>
<td>Centralized SCM</td>
<td>950000</td>
<td>1.315692E+08</td>
<td>1.325193E+08</td>
</tr>
</tbody>
</table>

Benefit from Centralization = Rs. 0.30251E+08

### Table 5: Modeling Environment:- MATLAB - Distributor Leader - intlinprog solver

<table>
<thead>
<tr>
<th>Iteration</th>
<th>PAC(Rs)</th>
<th>DAC(Rs)</th>
<th>TC(Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iter 1</td>
<td>91618000</td>
<td>21264200</td>
<td>112882200</td>
</tr>
<tr>
<td>Iter 15</td>
<td>0</td>
<td>112845125</td>
<td>112845125</td>
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<tr>
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<td>21264200</td>
<td>21264200</td>
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</tbody>
</table>

Benefit from Centralization = Rs. 0.915E+08

### Table 6. Modeling Environment - MATLAB - Distributor Leader - linprog solver

<table>
<thead>
<tr>
<th>Iteration</th>
<th>PAC(Rs)</th>
<th>DAC(Rs)</th>
<th>TC(Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iter 1</td>
<td>8.5965E+07</td>
<td>2.1264E+07</td>
<td>1.0723E+08</td>
</tr>
<tr>
<td>Iter 15</td>
<td>8.9643E+04</td>
<td>1.0393E+08</td>
<td>1.0461E+08</td>
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<tr>
<td>Centralized SCM</td>
<td>0.0280</td>
<td>2.1264E+07</td>
<td>2.1264E+07</td>
</tr>
</tbody>
</table>

Benefit from Centralization = Rs. 0.83356E+08

### REFERENCES


[17] Wang.X. et al, Pre purchasing with option contract and coordination in a relief supply chain, Int. J. Production Economics,
