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Optimizing the supply chain configuration with supply disruptions

Ruiqing Xia and Hiroaki Matsukawa

Keio University, Yokohama, Japan
matsukawa@ae.keio.ac.jp

Abstract. The purpose of this paper is to investigate a supplier-retailer supply chain that experiences disruptions in supplier during the planning horizon. There might be multiple options to supply a raw material, to manufacture or assemble the product, and to transport the product to the customer. While determine what suppliers, parts, processes, and transportation modes to select at each stage in the supply chain, options disruption must be considered. In this paper, we show that changes to the original plan induced by a disruption may impose considerable deviation costs throughout the system. When the production plan and the supply chain coordination scheme are designed in a static manner, as is most often the case, both will have to be adjusted under a disruption scenario. Using dynamic policies, we derive conditions under which the supply chain can be coordinated so that the maximum potential profit is realized.

Keywords: supply chain management; disruption management; inventory optimization

Introduction

A supply chain is the application of processes and tools to ensure the optimal operation of a manufacturing and distribution supply chain. This includes the optimal placement (including safety stock) of inventory within the supply chain, minimizing operating costs. The mathematical modeling techniques are often involved. These models are strategic in the sense that they optimize both safety stock levels and safety stock holding locations across the supply chain. There has been significant advancement in the safety stock optimization strategies in the last few decades. There are two main reasons for this. First, the past decades has seen a diffusion of supply chain knowledge throughout the organization. This diffusion of knowledge enables companies and managers to analyze and model supply chain. Second, more advanced tools including computer softwares are made that business users can use to actually perform the analysis.

With the development of supply chain models, more aspects of the chain that the companies and managers and business users need to concern. Among them is the single or dual sourcing and supply disruptions. When setting up an inventory policy, first of all it has to be decided whether to source all of the replenishment from one supplier, or to divide the orders among dual sources. To dual source means to use two preferred suppliers to provide the same product or service. To single source means to use just one preferred supplier, despite there being multiple capable suppliers available. Both single sourcing and dual sourcing have their own advantages and disadvantages.

The selection of suppliers heavily depends on the purchase price and the lead time characteristics of the suppliers. Often the choices are made either for an expensive and flexible (for example choices with short lead time) suppliers or cheap but rigid suppliers. Yet, it may be profitable to use two suppliers. Many purchasers decide to single or dual source based on certain assumptions.

Supply disruptions may be caused by diverse reasons including nature disasters, equipment failures or damaged facilities, during which a supplier cannot fulfill customer orders and then influence flows of the whole supply chain (Chen, H.Zhao and X.Zhao, 2012). Supply chain disruption has been proven to have seriously negative impact on corporate profitability and shareholder value. In order to cope with uncertainty in inventory systems, buffers are held to protect service performance against unforeseen events. If distribution takes place at various stages, the problem becomes more complex because of additional opportunity of allocating buffers to the stage of the systems. One of the most common policies for mitigating the disruption risk is to follow multiple-sourcing.

Many papers have contributed to optimize safety stock levels for supply chains. Inderfurth (1993) considers the optimization of safety stock costs and lead times for a single production process production multiple end items. Geoffrion and Powers (1995) describe the evolution in the network design field which focuses on developing the optimal manufacturing and distribution network for a company's entire product line. Network design focuses more on the two or more echelons in the supply chain for multiple products. Ettl*et al*. (2000) Graves and Willems (2000) and Graves and Willems (2005) also address the optimizing safety stock placement across the supply chain.

In this paper, we investigate a supplier-retailer supply chain that in which the suppliers may have the probability of disruptions during the planning horizon. The model under investigation is mostly related to Graves and Willems (2005). Yet, more aspects are concerned based on the origin model. We extend the Graves and Willems (2005) model to dual sourcing strategy and also the disruption risk is added.

The structure of this paper is shown as follow. In section 2, we introduce the assumptions. The model is formulates in section 3 and in section 4 we will show the dynamic programming method we use to solve the problem. A numerical case is provided in section 5 and we conclude the paper in section 6.

Assumptions

Multi-Stage Networks

The supply chain is modified as a network in which are arcs, stages and nodes. Arcs denote the upstream stages supply downstream stages. Stages represent the major processing function in the supply chain. It could be the production of a component, or the assembly or a raw material. Nodes denote the options for the stages. A node might be a supplier or an assembly center. An option at a stage is characterized by its added cost and lead time. The lead time is the time to perform the function at a stage when the stage reorders, provided all the inputs available. We assume the lead time is deterministic.

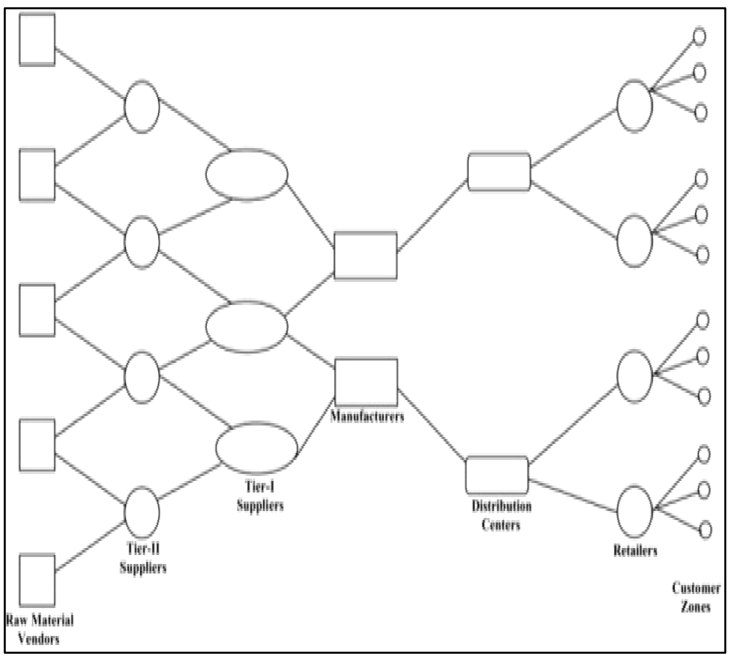

Fig 1. A typical construction supply chain network

Replenish Policies

All stages operate with a periodic-review base-stock replenish policy with a common review period. For each period, each stage observes the demand either from its downstream stages or an external customer, and orders are placed on its supplier to replenish the observe demand. No time delay in ordering need to be concerned. Hence, in each period all stages see the customer demand.

Guaranteed Service Times

We assume that each demand node *j* promises a guaranteed service time $S_j^{\{out\}}$. Which means, the customer demand at time t, the demand at stage *j* in period *t*, $d_j(t)$, must be filled by time t+$S_j^{\{out\}}$. Furthermore, we assume that stage *j* provides 100% service for the specified service time: stage *j* delivers exactly $d_j(t)$ to the customer at time t+$S_j^{\{out\}}$.

We assume that an internal stage *i* quotes the same outbound service time, $S_i^{\{out\}}$ to all its downstream customers. We also define $S_i^{\{in\}}$ as the inbound service time for stage *i*, which is the time to receive all the required inputs from the suppliers when stage *i* reorders. Also, we assume that for stages with one or more upstream adjacent stages, the inbound service time for stage *i* equals to the maximum of the service times of its suppliers.

Demand Process

An internal stage has only internal customers or successors; its demand in period *t* is the sum of the orders placed by its immediate successors. According to the base-stock policy, the demand at internal stage *i* is

$$d_i(t) = \sum_{(i,j)\in A} d_j(t)$$

where *A* is the arc that represents the network of supply chain. Without loss of generality, we assume that if there is an arc that from *i* to *j*, then one unit of *j* is produced by one unit of *i*. The average demand rate for stage *i* is

$$\mu_i = \sum_{(i,j)\in A} \mu_j$$

Consider a typical assumption where demand for end item *j* is normally distributed each period and *i.i.d.*, with mean μ and standard deviation σ. For the purposes of positioning safety, the demand bounds at the demand node might be specified by: where *k* represents the percentage of time that the safety stock covers the demand variation. The choice of *k* indicates how frequently the decider is willing to resort to other tactics to cover demand variability.

We assume for any period *t* and for any *m*, there is

$$D_j(\tau) \geq d_j(t-\tau+1) + d_j(t-\tau+2) + ..d_j(t)$$

Sourcing Strategy

In this paper, we assume the sourcing strategy follows dual sourcing. Each demand node chooses two suppliers from the upstream supply stages. Furthermore, we assume the rule refers the 80/20 rule, which means, each demand node will order 80% of the total demand from one of the supplier and order the rest 20% of the total demand from the other one. We assume the outbound service time of each supply stage equals to the maximum of the two suppliers of current supply stage, which indicates that the demand stage cannot start to produce before the arrival of all the demand.

Supply Disruption Risk

We assume that some suppliers may have the probability to disrupt. When the disruption occurs, according to the contract, the demand stages decide to stick to the original suppliers instead of choosing another one. Hence, to avoid out of stock when demand arrives, the extra stock is needed. The extra stock will not be used unless the disruption occurs. We define the ρ_i as the probability that the selected node stage *i* does not work when order arrives. We assume the disrupted node needs certain period to recover, which, however, is not considered in this paper. That is, when disruption occurs, the suppliers must use the extra stock to make sure demand will be fulfilled and manage to recover in the certain period. Meanwhile, the demand stage only concern about if the demand arrives in time. The extra safety stock is as follows $SS_i^e = D_i(t_i)\rho_i^2$ where t_i is the lead time of the selected node at stage *i*.

Optimization Model

The supply chain configuration problem is based on the Graves and Willems model (2005) and is formulated as follows. There are three terms in the function. The first term represents stage i's safety stock cost, which is a function of the stage's net replenishment time extra safety stock and demand characterization. The cumulative cost of the product at stage i times the holding cost rate makes the holding cost. The second term represents the pipeline stock cost. The third term represents the COGS (cost of goods sold), which is the total cost of all the units that are delivered to customers during the company-defined interval of time. Constraints assure that the service times are feasible.

$$min \sum_{i=1}^{N} [\alpha c_i [D_i(s_i^{in} + t_i - s_i^{out}) - (s_i^{in} + t_i - s_i^{out})\mu_i + SS_i]$$

$$+\alpha(c_i - \frac{\chi_i}{2})t_i\mu_i + \beta\chi_i\mu_i]$$

s.t.

$$s_i^{in} \geq s_j^{out} \geq 0 \quad for\ i = 1, 2, ..., N, j : (j, i) \in A$$

$$s_i^{in} + t_i - s_i^{out} \geq 0 \quad for\ i = 1, 2, ..., N$$

Formulation

We solve the configuration formula by decomposing the problem into *N* stages, where *N* is the number of nodes in the supply chain spanning tree. The dynamic program evaluates a functional equation for each node from 1 to *N*. The solution of the configuration problem for the sub graph N_i will be the solution at each node.

$$E_{ij}(s^{in}, c^1, s^{out})$$

$$= \alpha c^a[D_i(s^{in} + T_{ij} - s^{out}) - (s^{in} + T_{ij} - s^{out})\mu_i + SS_i]$$

$$+\alpha(c^a - \frac{C_{ij}}{2})T_{ij}\mu_i + \beta C_{ij}\mu_i + \sum_{k:(i,k)\in A,\ k<i} g_k(c^a, s^{out})$$

$$+min_{\sum_{h:(h,i)\in A,\ h<i} c_h = c^2} \sum_{h:(h,i)\in A,\ h<i} f_h(c_h, s^{in})$$

We define E_{ij} as the supply chain cost for the subnetwork with node set N_i when node *j* is chosen at stage *i*. The function of E_{ij} is as follows. Where $c^a = c^1 + C_{ij}$. c^1 is the cumulative cost of all of the upstream adjacent stages. The first three terms represent the safety stock cost, the pipeline stock cost and COGS, respectively. The fourth terms represents the nodes that are downstream from node *i*. The fifth terms represents the nodes that are upstream from node *i*.

We evaluate f_i for the downstream from thr current node as follows.

$$f_i(c^a, s^{out}) = minE_{ij}(s^{in}, 0, c^a - C_{ij}, s^{out})$$

Dynamic Program

The dynamic programming algorithm is used to solve the problem with *N* stages as follows:

1. *For i =1 to N-1, evaluate $f_i(c^a, s^{out})$ for s^{out} =0,1,…,M_i, where M_i is the maximum possible replenishment time for node I as*
   $M_i = max[T_{ij}|j : 1 \leq j < O_i] + max[M_h|h : (h,i))]$
   where O_i is the number oof candidate options at stage i.
2. *For i = N, evaluate $f_i(0,s^{in})$ for s^{in} = 0, 1,…M_i*
3. *Minimize $f_N(0,s^{in})$ for s^{in} = 0, 1,…M_N in order to find the value of optimal objective function.*

The standard backtracking procedure of the dynamic program can be used to find the optimal set of service times and options.

Numerical Simulation

In this section, we present numerical example. The construction of the case is shown as Fig.2. We consider the case as a cell phone supply chain with parts suppliers (as stage 1, 2 and 3), assembly centers (as stage 5, 7 and 8), battery supplier(as stage 4), screen display (as stage 6) and demand (as stage 9).

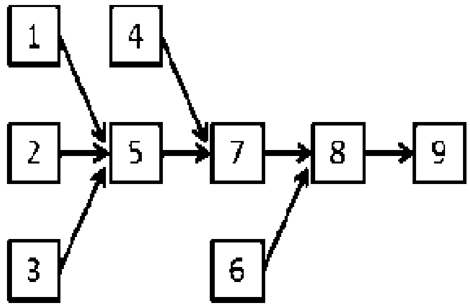

Fig. 2. Case Simulation

Data

The parameter values are illustrated in Table 1. Table 2 shows the set of the nodes of all the stages.

Results

Table 3 shows case 1, in which the optimal solution of the supply chain using dual sourcing strategy, where no disruption is considered. We assume the case 2, in which the disruption may happen at stage 5 and the disruption probability follows 5%. We list the solution of supply chain with disruption occurs in Table 3. The total supply chain cost in figure equals to 414.08K. Furthermore, the cost of figure is 419.54K. This increases the cost of no disruption supply chain cost by 1.32%. Notice that in the above case we assume that any supplier that are under disruption will be abandoned. However, in the real world, the demand stage may not be able to change the suppliers in a short period. Hence, instead of the changing supplier policy, we assume the supplier which has a probability to disrupt holds the extra safety stock. This extra safety stock follows the definition of the previous section of this paper. Therefore, under this condition, we have another result with the same nodes option as shown in the tables but a different total cost which equals to 418.49K. This increases the cost of case 1 by 1.07% but decreases the cost of case 2 by 0.25%.

Table 1. Parameter values

μ	125
σ	80
κ	1.645
α	0.45
β	1

Table 2. Set of the nodes of all the stages

Stage	Option	Cost Added	Leadtime
1	1	12	5
	2	8	8
	3	4	13
2	1	5	15
	2	8	12
	3	12	9
3	1	12	10
	2	8	12
	3	5	15
4	1	10	12
	2	12	9
5	1	3	18
	2	13	12
	3	20	10
6	1	7	8
	2	9	6
	3	4	12
7	1	8	10
	2	6	12
8	1	10	10
	2	6	14
	3	12	8
9	1	7	8
	2	9	6
	3	4	12

Table 3. Case using dual sourcing strategy

Stage	Option	Cost Added	Leadtime	Proportion
1	2	8	8	20%
	3	4	13	80%
2	1	5	15	80%
	2	8	12	20%
3	2	8	12	20%
	3	5	15	80%
4	1	10	12	80%
	2	12	9	20%
5	1	3	18	80%
	2	13	12	20%
6	1	7	8	20%
	3	4	12	80%
7	1	8	10	20%
	2	6	12	80%
8	1	10	10	20%
	2	6	14	80%
9	1	7	8	80%
	2	9	6	20%

Conclusion and Further Research

In this paper, we introduce and extend a model for configuration new supply chain, in which the safety cost, pipeline cost and COGS are considered. Moreover, we take in account the dual sourcing strategy instead of single sourcing. Through numerical simulation, we provide results which may lighten the decision makers. As for future research, further extensions are necessary for processes of stochastic structure.

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