COLLABORATIVE SCHEDULING MODEL FOR SUPPLY-HUB MANAGEMENT

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Supply-hubs, supported by information sharing technologies, are being used by contract manufacturers in hi-tech industries to streamline their supply-side inventory management, in response to shortening product lifecycles and the necessity of configuring goods to order. In this paper, we develop a linear programming model for integrated planning and scheduling of supply hub activities. We assume that all stakeholders in the supply hub share information on their capacities, schedules and cost structures. Based on this information the model addresses the issue of production and delivery scheduling, for the manufacturer and its suppliers, for optimal profit. The model was solved using optimization tools provided by ILOG.

Keywords : Supply Hub, Collaborative Scheduling, Hi-tech supply chain.

1. INTRODUCTION

The tide of constant innovation, changing market forces and rising customer expectations have transformed the hi-tech and electronics industry into one of the most competitive industries. Challenges in dealing with mass customization, rapidly shrinking product life cycles, rapid inventory depreciation and handling complex multi-sourced supply chains have required the use of very sophisticated tools and techniques for meeting the rising expectations of customers in a cost-efficient manner. Two of the most effective approaches to managing the electronics supply chain include the usage of collaborative planning through visibility enabled by the Internet and the usage of supply hubs to manage material flows and supplier relations [1].

Traditionally, activities have been optimized within the functional and corporate silos, at the expense of the greater supply chain [2]. Such a model for the electronics supply chain is unsuitable under the current strict requirements of the industry. Hence, the greatest opportunity today, for electronic supply chains lies in the usage of Internet-based systems to share operational information to improve synchronization and coordination between the various supply chain activities, leading to greater flexibility and responsiveness, without the requirement of maintaining expensive and quickly ageing inventory.

However, in terms of inventory management supply chain efficiency is being particularly enhanced through the establishment of supply hubs. Supply Hubs have developed from the successes of the Vendor Managed Inventory (VMI) initiatives in the grocery industry, wherein an agreement is reached between the supplier and the customer whereby the supplier manages the customer's inventory at the customer's facility or retail outlet. It is up to the supplier, given his operational constraints and commitments, to decide the best possible manner and time to replenish the customer's inventory, while satisfying the minimum service level requirements agreed upon with the customer [3]. Supply hubs are particularly suited to the electronics supply chain.

From the various implementations of supply hubs today, a supply hub maybe defined as a facility which is typically located close to a manufacturer's production center where all or some of its supplies are warehoused with the agreement that the materials will be paid for only when consumed. The main function of the supply hub is to smoothen the availability of components on the supply side and to ensure that there are enough components to support the manufacturer's assembly or production activities. However, since the manufacturer takes ownership of the various components supplied by multiple suppliers only when it is being used, the manufacturer is able to maintain access to a ready supply of inventory at little or no inventory holding costs. There are however, variations in how the supply hub operations are designed and implemented, particularly with regards to the instant at which the payment for the material becomes effective. Also, very commonly the supply hub is located in the premises of a third party logistics (3PL) who had been outsourced the management of the supply hub, but in certain cases the supply hub may also be hosted within the manufacturer's facility [3,4,5].

In practice, a minimum of around two weeks inventory is maintained in the supply hub. This allows the manufacturer to assemble-to-order and deliver to its customer in a timely manner. The supply hub arrangement is lucrative from the manufacturer's standpoint. However, the supplier's are squeezed of their margins, since they have to bear the inventory holding and capital costs, as well as the obsolescence costs.

One of the main issues involved in the management of supply hubs include maintaining adequate levels of inventory for all needed components, in order to meet the needs of the customer. Furthermore, lower inventory levels may be achieved through optimal supply chain performance in the form of synchronized production, transportation and assembly. This has be achieved while keeping in mind the capacity constraints of the supply chain, the need to ensure that supplies from various suppliers are available for kitting at the same time, regardless of the various lead times of the suppliers, and the various inventory holding and production costs of the supply chain.

1.1 Literature Survey

Due to the fact that supply hubs are a very recent phenomenon, there is very little literature available specifically on this topic. Furthermore of the available literature on supply hubs much of it is focused on understanding the business and contractual issues and impacts of supply hub programs in different companies. Laura R Kopczak [4] undertook one such study on the strategies adopted by Apple Computers in the setting up of supply hubs at three of their production sites. She also presents a strong case for the establishment of such facilities by listing down the benefits to the company. Zuckerman [5] describes a similar effort undertaken by Compaq Computer at its Houston production facility. Saccomano [6] describes the efforts of Circle International in the setting up of Vendor Hubs in the Asian region.

There is however significant literature on supplier relations and inventory management policies in the operations research and management sciences field. Most of the discussion on issues related to supply hubs is available therein in the context of just-in-time (JIT) manufacturing and VMI. Erenguc et al. [7] review and discuss some of the characteristics of JIT manufacturing and inventory management policies as presented in various papers. Waller et al. [3] try to quantify, through simulations, the benefits of adopting VMI in scenarios of demand variability, partial adoption of VMI and limited manufacturing capability. Achabal et al. [8] develop a decision support system for VMI through forecasting and better inventory management.

Thus in the literature, most efforts have revolved around VMI and JIT manufacturing, which are closely related to supply hubs. Our research attempts to further this research to concentrate specifically on the dynamics of supply hubs. In this paper, we develop a collaborative scheduling model that optimally schedules the supply chain activities to meet the requirements at the supply hub.

2. PROBLEM FORMULATION

We consider the supply hub management problem, for a supply hub stocking components for a large original equipment manufacturer (OEM). The OEM has special agreements with the supply hub manager and its 1st Tier Suppliers, which ensure that the assembly-part inventories in the supply hub are adequate to meet the daily requirement of the OEM. The 1st Tier Suppliers in turn will rely on the 2nd Tier Suppliers to provide the needed components in a timely manner so as to enable them to meet their commitments, on the assembly-parts, to the OEM. A representation of the supply chain is presented in Figure 1.

The supply hub owner has information on the daily requirements of the OEM and the cost of inventory for all the assembly-part inventories stored in the supply-hub. Information is also available on the production and inventory costs and capacities, for all assembly-parts, of all the 1st Tier Suppliers and the transportation costs from their facilities to the supply hub. Similarly, information is also available on the costs and capacities of the 2nd Tier Suppliers and their transportation costs to the 1st Tier Suppliers. Hence, with access to all this operational information on all the supply chain participants in an electronics supply chain the challenge is how best to schedule all the production and distribution activities leading to minimal operational cost, while maintaining adequate inventory levels at the supply hub.

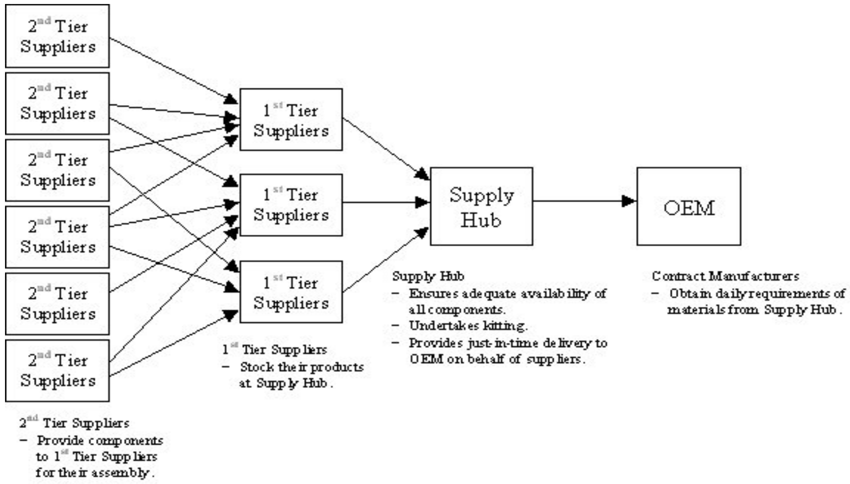

Figure 1 : Electronics Supply Chain with OEM Supply Hub.

2.1 Notation

For development of a mathematical model for the above scenario, the following notations were used.

<u>Identifiers</u>

r	: Component type identifier.	R	: Number of component types.
v	: 2nd Tier Suppliers identifier.	V	: Number of 2nd Tier Suppliers.
i	: Assembly-part type identifier.	I	: Number of assembly-part types.
j	: 1st Tier Suppliers identifier.	J	: Number of 1st Tier Suppliers.
l	: Brand Identifier.	L	: Number of Brands.
t	: Time Period identifier.	T	: Total time horizon of the model.

<u>Superscript Identifiers</u>

K : Supply Hub Identifier.
M : OEM Identifier.

<u>Parameters</u>

C_{abt} : Maximum production capacity available for component/assembly-part of type a offered by 2nd Tier Supplier/1st Tier Supplier b in time period t.

P_{ab} : Unit cost price for component/assembly-part of type a procured from 2nd Tier Supplier/1st Tier Supplier b.

T_{abdt} : Maximum transportation capacity for shipment of component of type a from 2nd Tier Supplier b to its customer d in time period t.

U_{abdt} : Unit transportation cost for shipment of component of type a from 2nd Tier Supplier b to its customer d in time period t.

W_{ab} : Unit inventory cost incurred for component/assembly-part of type a in the possession of 2nd Tier Supplier/1st Tier Supplier b.

R_{ab} : Units of component type a required in the production of one unit of assembly-part b.

M_{ab} : Units of assembly-part type a required in the putting together 1 kit for brand type b.

Variables

Q_{abt} : Quantity produced for component/assembly-part of type *a* by 2nd Tier Supplier/1st Tier Supplier *b* in time period *t*.

I_{abt} : Inventory of component/assembly-part of type *a* with 2nd Tier Supplier/1st Tier Supplier *b* in time period *t*.

S_{abdt} : Quantity shipped of component/assembly-part of type *a* from 2nd Tier Supplier/1st Tier Supplier *b* to its customer *d* in time period *t*.

2.2 LP Model

We now develop a linear programming model for the management of a supply hub. The objective of the model was to minimize the cost of procurement for the OEM, with the usage of the supply hub, while being constraint by various capacity and flow balancing constraints.

Objective, minimize cost:

$$
\begin{aligned}
MinCOST \quad = & \\
& \left[\sum_{r=1}^{R} \sum_{v=1}^{V} \sum_{j=1}^{J} \left(\sum_{t=1}^{T} S_{rvjt} U_{rvjt} + P_{rv} \sum_{t}^{T} S_{rvjt} \right) \right. \\
& + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left(\sum_{t=1}^{T} S_{ijkt} U_{ijkt} + P_{ij} \sum_{t}^{T} S_{ijkt} \right) \\
& \left. + \sum_{l=1}^{L} \sum_{k=1}^{K} \sum_{m=1}^{M} \left(\sum_{t=1}^{T} S_{lkmt} U_{lkmt} + P_{lk} \sum_{t}^{T} S_{lkmt} \right) \right] \\
& + \left[\sum_{i=1}^{T} \left(\begin{aligned} & \sum_{r=1}^{R} \sum_{v=1}^{V} W_{rv} I_{rvt} + \sum_{r=1}^{R} \sum_{j=1}^{J} W_{rj} I_{rjt} \\ & + \sum_{i=1}^{I} \sum_{j=1}^{J} W_{ij} I_{ijt} + \sum_{i=1}^{I} \sum_{k=1}^{K} W_{ik} I_{ikt} \\ & + \sum_{l=1}^{L} \sum_{k=1}^{K} W_{lk} I_{lkt} + \sum_{l=1}^{L} \sum_{m=1}^{M} W_{lm} I_{lmt} \end{aligned} \right) \right]
\end{aligned}
\quad \ldots (1)
$$

Subject to,

Capacity Constraints:

$$Q_{rvt} \le C_{rvt} \qquad forall \qquad r \in R, v \in V \;\&\; t \in T$$

$$S_{rvjt} \le T_{rvjt} \quad forall \quad r \in R, v \in V, j \in J \;\&\; t \in T$$

$$Q_{ijt} \le C_{ijt} \quad forall \quad i \in I, j \in J \;\&\; t \in T$$

$$S_{ijt}^{K} \le T_{ijt}^{K} \quad forall \quad i \in I, j \in J \;\&\; t \in T$$

$$Q_{lt}^{K} \le C_{lt}^{K} \quad forall \quad l \in L \;\&\; t \in T$$

$$S_{lt}^{KM} \le T_{lt}^{KM} \quad forall \quad l \in L \;\&\; t \in T$$

…(2)

Inventory Flow Constraints:

$$I_{rv(t-1)} + Q_{rvt} = \sum_{j=1}^{J} S_{rvjt} + I_{rvt} \quad forall \quad r \in R, v \in V, j \in J \;\&\; t \in T$$

$$I_{rj(t-1)} + \sum_{v=1}^{V} S_{rvjt} = \sum_{i=1}^{I} R_{ir} Q_{ijt} + I_{rjt} \quad forall \quad r \in R, v \in V, j \in J, i \in I \;\&\; t \in T$$

$$I_{ij(t-1)} + Q_{ijt} = S_{ijt}^{K} + I_{ijt} \quad forall \quad i \in I, j \in J \;\&\; t \in T$$

$$I_{i(t-1)}^{K} + \sum_{j=1}^{J} S_{ijt}^{K} = \sum_{l=1}^{L} M_{li} Q_{lt}^{K} + I_{it}^{K} \quad forall \quad i \in I, j \in J, l \in L \;\&\; t \in T$$

$$I_{l(t-1)}^{K} + Q_{lt}^{K} = S_{lt}^{KM} + I_{lt}^{K} \quad forall \quad l \in L \;\&\; t \in T$$

$$I_{l(t-1)}^{M} + S_{lt}^{KM} = I_{lt}^{M} \quad forall \quad l \in L \;\&\; t \in T$$

…(3)

Materials Availability at time of production and kitting:

$$I_{rj(t-1)} \ge \sum_{i=1}^{I} R_{ir} Q_{ijt} \quad forall \quad r \in R, i \in I, j \in J, t \in T$$

$$I_{i(t-1)}^{K} \ge \sum_{l=1}^{L} M_{li} Q_{lt}^{K} \quad forall \quad i \in I, l \in L \;\&\; t \in T$$

…(4)

OEM minimum service level constraint:

$$I_{it}^{K} \geq I_{i}^{K\,\min} \qquad forall \qquad i \in I \ \& \ t \in T \qquad \ldots(5)$$

OEM demand fulfillment constraint:

$$I_{lt}^{M} = Q_{lt}^{M} \qquad forall \qquad l \in L \,\&\, t \in T \qquad \ldots(6)$$

The solution of this model determines the selection of suitable 1st Tier and 2nd Tier suppliers who can meet the service level required at the supply hub in a cost effective manner, and also provides a schedule for production and assembly activities within the supply chain. With the above mathematical model any of the available optimization toolkits might be used in order to generate the optimal schedules for the supply hub management.

3. SOLUTION

3.1 ILOG OPL Studio

The above linear model was developed and optimized in the commercial optimization program, OPL Studio available from ILOG. ILOG provides a very comprehensive library of optimization algorithms implemented in C++. These algorithms can be used for the solution of a varied number of large-scale linear, integer or constraint programming models. ILOG also incorporates a set of modeling concepts, such as activities and resources, which are very useful in the solution of scheduling and allocation problems. ILOG studio utilizes the Optimization Programming Language (OPL) for modeling of problems. User-defined search strategies for each model can be specified in order to reduce the computational power required for the solution.

3.2 Computational Complexity

The LP model for supply hub management was developed in ILOG and solved for a scenario with 1 supply hub located very near a single OEM, 5 1st Tier Suppliers supplying 4 assembly-parts to the supply hub and 8 2nd Tier Suppliers selling 16 types of components. Not all 1st Tier Suppliers manufacture all assembly-parts or all 2nd Tier Suppliers supply all component types. These facilities were all connected to each other through a logistics network. The time horizon for the model was taken as 12 periods. The number of variables that were encountered was 22,166 and the constraints numbered 25,223. The solution time was less than 10 seconds. An analysis of some of the results from the optimization exercise is presented in the following section.

4. COMPUTATIONAL RESULTS

In order to verify the optimized nature of the model that was developed in earlier sections, the model was solved for a given demand pattern from the OEM and the scheduling of activities in the supply chain was observed. The analysis for supplies for a particular component, from two 1st Tier Suppliers, to the supply hub is analyzed. Similar analysis can be conducted for other components and other 1st Tier and 2nd Tier Suppliers.

As shown in Figure 2 the OEM demand for periods 8 to 12 was available. Also the details on the production capacity and the logistics shipment capacity for the 1st Tier Supplier were available. We notice from the data that firstly production is scheduled nearer or in the period of shipment, due to the fact that the model tries to cut down on the inventory holding costs and tries to synchronise the production activity with the schedule of the logistics service provider. Furthermore, production and shipment to the supply hub at the suppliers end is scheduled closer to the date at which the OEM requires the components, further optimizing the inventory level at the supply hub. The reason that production and shipment first start in the period 4 is that the supplier is waiting for the delivery of components from 2nd tier suppliers who fulfill the order of the 1st Tier Supplier by time period 3.

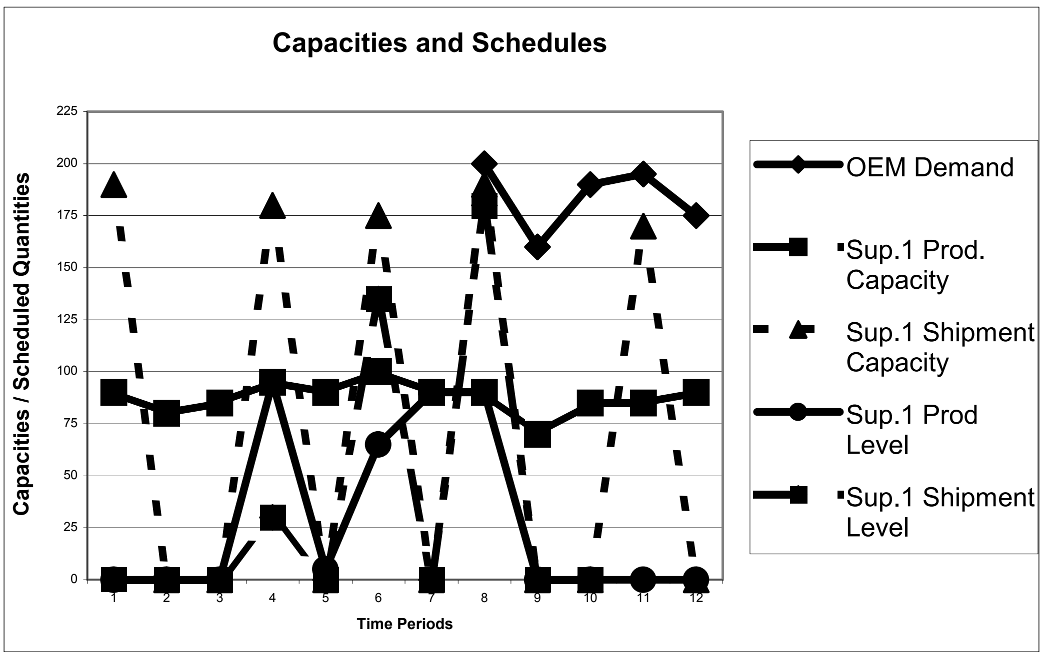

Figure 2: Capacities and Schedules for 1st Tier Supplier 1 for Component 1.

Similar results are obtained for the second 1st Tier Supplier supplying the same component. In fact, as seen in Figure 3 production is so well synchronized with the schedule of the logistics service provider that whatever is produced is shipped off in the same time period. Furthermore, production and shipment pick up closer to the date of requirement of the OEM. Production and shipment continues to the end (during periods 10 to 12) as this supplier is chosen due its lower price to maintain the minimum inventory level for the component in the supply hub.

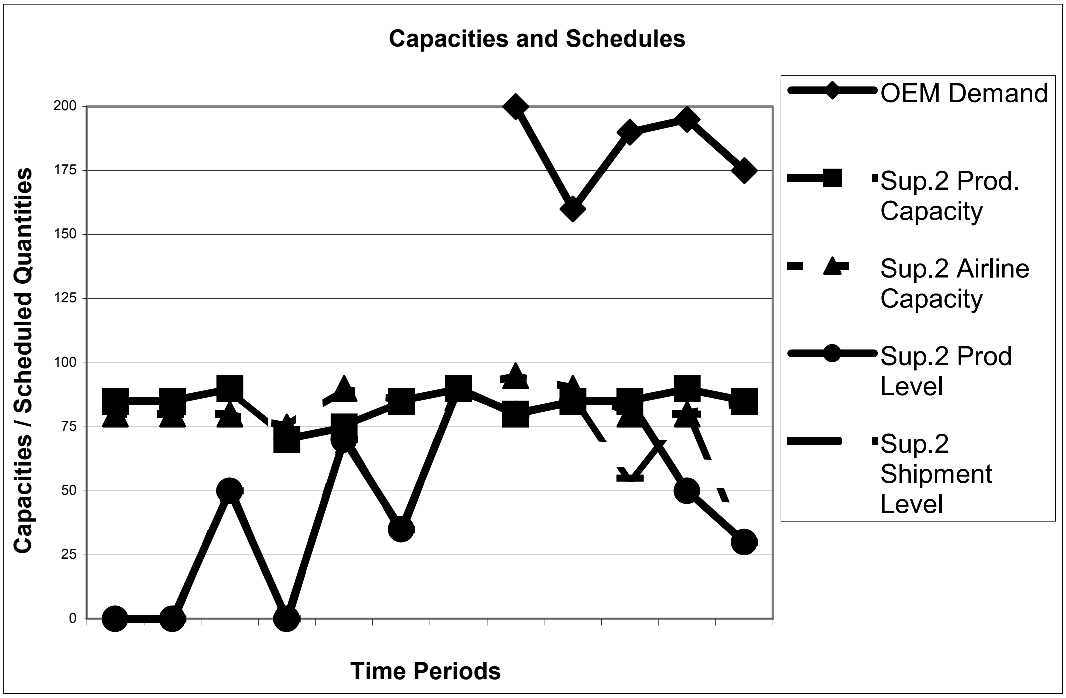

Figure 3: Capacities and Schedules for 1st Tier Supplier 2 for Component 1.

As stated earlier a similar analysis can be carried out for the remainder of the participants in the supply chain.

5. CONCLUSION

In this paper we have formulated and solved a collaborative scheduling model for supply hub management. This model is especially useful for inventory management in the electronics supply chain. Our formulation here, which is linear and uses a LP model, provides a good planning tool to schedule production and shipment activities down the supply chain in line with the requirements of the OEM. We have assumed the availability of operational information in each stage of the supply chain to all the supply chain partners, which might not be the case in the real world.

6. REFERENCES

[1] Adexa Inc. White Paper, "The Electronics Supply Chain: Winning in a Virtual Environment", *(http://www.adexa.com)*

[2] N. Viswanadham, "Analysis of Manufacturing Enterprises – An Approach to Value Delivery Processes for Competitive Advantage", Kluwer Academic, Boston, 1999.

[3] Matt Waller, M. Eric Johnson and Tom Davis, "Vendor-Managed Inventory in the Retail Supply Chain", *Journal of Business Logistics,* Oak Brook 1999.

[4] Laura Rock Kopczak, "Case 6-1: Apple Computer's Supplier Hubs: A Tale of Three Cities", in "Global Operations and Logistics: Text and Cases", John Wiley & Sons, March 1998.

[5] Amy Zuckerman, "Compaq Switches to Pre-Position Inventory Model", *World Trade*, April 2000 72-74.
[6] Ann Saccomano, "What's Good in Asia", *Traffic World*, April 12, 1999 47-48.
[7] S. Selcuk Erenguc, N.C. Simpson, Asoo J. Vakharia, "Integrated production/distribution planning in supply chains: An invited review", *European Journal of Operational Research*, 115 (1999) 219 – 236.
[8] Dale D. Achabal, Shelby H. McIntyre, Stephen A. Smith and Kirthi Kalyanam, "A Decision Support System for Vendor Managed Inventory", *Journal of Retailing*, Volume 76(4) 430-454.