

A Supply Chain Model for Lean Facilities Considering Milk Run Replenishment, Postponement Production System and One-for-One Base Stock Inventory Policy Decisions

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Abstract

In today's competitive world and globalization of the market economy, customer's preference shifted to more personalized products to suit their everyday requirements. Thus, effective supply chain management is increasingly becoming an effective tool to gain competitive advantage coupled with lean and agile concepts. A mixed integer non-linear programming model was formulated for a supply chain with four echelons. Bayesian demand forecasting method was also used which aids in the decision of postponement. Postponement's desirability was affected by the demand and variability. Milk run desirability was affected by actual due dates of customers, RM holding costs and direct fixed costs.

Keywords

Agile Manufacturing, Inventory Management, Lean Manufacturing, Supply Chain Management

1. Introduction

The society has moved into an age where customers are harder to please, wanting more personalized products to suite their everyday needs and wants. This change in customer preference brought about pressure to companies to find new ways to create and deliver value to customers at the right place at the right time. In turn, this resulted for companies to adopt and develop complex supply chain models to gain competitive advantage in their respective industries. To take advantage of supply chains and gain competitive advantage, companies should consider effective supply chain management.

Lean manufacturing is beginning to gain popularity as it is being incorporated into the supply chain in order to yield cost reduction. Lean manufacturing focuses on the elimination of waste, flexibility and response to customer needs. Pursuing a lean manufacturing environment requires the reduction of on-hand inventory yet agile enough to deliver customer needs at the right time. Presently, numerous supply chain researches have created different mathematical models which embraced the concepts of lean and showed quantified benefits of implementing these lean principles. Some of these are the works of Wang and Sarker [1], Naso et al. [2], and Kabling [3]. These past researches, however, have focused mainly on the lean concept alone thus their models will possess the weaknesses of the lean concept. Some of which are low robustness (ability to withstand disturbances or fluctuations in demand) and unable to quickly configure a variety of products at short notice. According to Xu Xuejun & Zhiyong [4] combining lean and agile paradigms will provide more benefits as compared to isolating a paradigm. The combination of the lean and agile strategies in a single system is called leagility, as coined by Naylor et al and cited by Naim, M.M. & Gosling, J. [5].

According to Xu Xuejun & Zhiyong [4], agile manufacturing focuses on the ability to react quickly to changes in demand, in terms of volume and variety, while in terms of a supply chain environment agility aims to carry

inventory as generic as possible. Market knowledge and forward planning is the key component of agile manufacturing to counter sudden demand variability and disturbances. Lean and agile principles showed great importance in the use of market knowledge, value stream, lead time reduction, and elimination of waste. The difference of lean and agile is that agile puts more consideration to rapid reconfiguration of products to meet customer wants at short notice. Agile is also flexible to robustness or sudden variation in demand and disturbances while lean focuses on smooth demand or little demand variation. Xu Xuejun & Zhiyong [4] also discovered that both paradigms can be combined together with the use of postponement to achieve the best of both paradigms. Huang & Liang [6] also cited that postponement could be used to achieve the benefits of mass customization by combining push and pull systems. According to de Kok et al. [7], postponement is an agile process wherein, the point where the final characteristic of the product is to be put together is suspended. Past studies that considered postponement include the works of Huang & Liang [6], Aviv & Fedegruen [8] and Mieghem & Dada [9].

Most agile researches have focused on the feature of postponement. Harrison [10] pointed out that the benefits of agile could be further improved if it is applied to the whole supply chain. The works of Huang & Liang [6] and Gui et al. [11] were found to integrate the postponement strategy in the supply chain. However as noted by Naim, M.M. & Gosling, J. [5], agility places less emphasis on efficiency, particularly in terms of cost. Thus the efficiency of the agile supply chain may be sub-optimized. Exploring the use of lean techniques to reduce cost and increase efficiency along with the flexibility of agile manufacturing integrated in a supply chain would fit very well to see the benefits in the whole perspective.

A number of concepts have been presented above which can further improve the present supply chain management but the challenge is to integrate these concepts into a single supply chain model. For this reason, this study aims to integrate operational-tactical aspects of a supply chain such as inbound logistics, replenishment frequency and inventory policy that is consistent with a lean and agile supply chain strategy such as postponement and pull production system in a multi-echelon, multi-product environment.

2. Systems Definition

This study deals with a four-echelon supply chain considering lean and agile principles of production and logistics in an operational-tactical point of view with multiple echelons, multiple sites per echelon, and multiple products in a single family. The first echelon consists of several facilities of the suppliers of raw materials. The second echelon consists of the facilities of the manufacturer or manufacturing plants where assembly and production takes place. The third echelon is made up of two types of facilities, warehouses and cross-docks. And finally the fourth echelon is made up of the customers or the end users of the products. The network topology in its entirety can be seen graphically in Figure 1. The system to be considered is a mix of arborescent and non-arborescent. The parts of the supply chain that is arborescent are the suppliers to the manufacturing plant since there is only one supplier for each raw material and the cross dock to customer delivery. In considering the inbound logistics, two choices can be made for the mode of replenishment namely the traditional direct replenishment or the lean logistics of milk run. For the outbound logistics, cross docking and warehouses are to be considered.

The manufacturer has different suppliers of different raw materials to produce the intermediate products that they have and the different raw materials needed to produce the finished products. Each supplier can produce one or many types of raw materials required by the manufacturing plants. However, only one supplier can produce each raw material part-type.

Processing of the raw materials take place in the manufacturing plant where two types of production output that can be produced. These are the finish goods (FG)-types and the intermediate products. Both will be produced using separate Kanban production lines. Furthermore, intermediate products for the Direct FG route and the Postponement route will have separate Kanban production lines. The intermediate goods produced are generic in nature and upon using postponement it will be customized based on customer preference at the warehouses or in the second stage of production in the manufacturing plant via, labeling, assembly, packaging or further manufacturing. The manufacturing plant also considers a pull system of production wherein operations in the plant are dependent on customer orders. The pull system in place at the manufacturing plant is the kanban system.

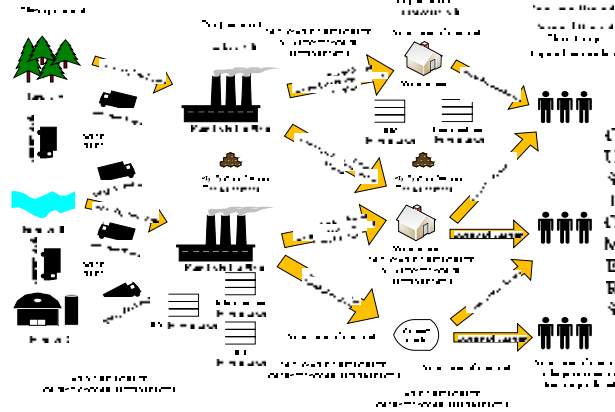


Figure 1: System Network Topology

The warehouses are the facilities that receive intermediate product and raw material part-type shipments from the manufacturing plants, which then store those shipments in its facility. These facilities have storage capacities for intermediate products and raw material part-types which it carries. Warehouses are capable of performing postponement activities, which transform the intermediate products into finished product-types, by performing final manufacturing, assembly and packaging of its carried intermediate product. Warehouses also employ a pull production system which is the CONWIP pull system to manage the flow of materials in its facility. Cross-docks are similar facilities to warehouses, except that it cannot store shipments that it receives from the manufacturing plants. It cannot perform postponement activities, thus only finish good product-types can pass through it. Cross-docks have a limited capacity in terms of the finished goods that can pass through it. Customers initiate the end demand within the supply chain. The quantity of the orders is stochastic in nature, which follows the normal probability distribution. Customers also require that a certain service level, which is the proportion of finished goods that are delivered on time, to be satisfied.

3. Model Formulation

Consider a supply chain for multiple products in a single product family with four echelons and multiple sites per echelon. Such that: each supplier, manufacturing plant, warehouse and cross-dock has a set of vehicles that have an aggregate capacity to deliver to the downstream facilities. It is assumed that manufacturing plants have milk run sets which determine which suppliers are included in a milk run trip; and manufacturing plants and warehouses use the base stock policy as their inventory policy. Set up times for manufacturing plants and warehouses are also assumed to be insignificant and thus will not be considered. In terms of postponement activities, it is assumed that there will only be one degree of postponement. Finally it is assumed that the demand of the customers follows the normal distribution. The indices to be used for the formulation of the model are as follows: c for customers, e for milk run set, f for finished goods, m for manufacturing plant, o for cross dock, r for raw material and w for warehouse.

3.1 Objective Function

The components of the objective function are the different costs incurred throughout the supply chain. These are the holding cost, shortage cost, replenishment cost, transfer cost, delivery cost, and backorder cost.

Holding cost is the cost of storing inventory at the different supermarkets at the end of the period. There are three types of holding costs since there are three types of inventory. These are the raw material, intermediate product and finished goods holding costs as shown in (1).

$$\sum_r \sum_m HC_r MRMLVL_{rm} + \sum_r \sum_w HC_r WRMLVL_{rw} + \sum_m \sum_t HC_t MINTRLVL_m + \sum_w \sum_o HC_o WINTRLVL_{wo} + \sum_f \sum_m HC_f MFGLVL_{fm} \quad (1)$$

Shortage cost is incurred by the system whenever the forecasted demand is less than the actual demand. Replenishment costs are the costs incurred by the system for replenishing raw materials at the manufacturing plants. There are three types: the milk run fixed costs which comprises of the ordering cost, the cost of setting up a milk run and the cost of the drivers and trucks used; the milk run variable costs and the direct replenishment fixed costs.

Direct replenishment fixed costs would be the costs incurred whenever a direct replenishment is used to replenish materials instead of a milk run. Transfer costs are the costs of transporting inventory in the middle part of the supply chain. There are three types of transfer costs: (1) Transfer cost of intermediate product from manufacturing plant to warehouse, (2) Transfer cost of raw materials from manufacturing plant to warehouse and (3) Transfer cost of finished goods from manufacturing plant to cross dock. These three have similar formulations, and is as follows: the product of the number of units to be transferred to another facility, the transfer cost per unit and the proportion that a specific facility will deliver to another facility and a conversion factor if needed. The conversion factor is used whenever two or more materials are stored in a single vehicle for transport. An example is shown in (2).

$$\sum_f \sum_m \sum_o TC_{mo} DEM_{fm}^{macro} PROP_{fmo}^{cross} \quad (2)$$

Delivery costs are incurred by the system for transporting finished products to the customers. There are two types of delivery costs: warehouse to customer and cross dock to customer delivery costs. They have similar formulations except that for the warehouse a proportion is needed since there are multiple warehouses. An example formulation is shown in (3) which is the delivery cost from warehouse to customer.

$$\sum_f \sum_w \sum_c DEL_{wc} DEM_{fw}^{war} PROP_{fwc}^{fgpost} \quad (3)$$

An order is considered backordered when the total lead time it requires to deliver the product to the customer is already greater than the due date that was negotiated with the customer. There are two possibilities that can lead to backordered units, the delay and the default on delivery schedule depending on whether the products were postponed or directly finished as well as the route from manufacturing plant to warehouse or cross dock to customer. If an order is backordered, backorder cost is incurred. The backorder cost function was derived using decision tree since there are several scenarios where delay may occur in direct FG route and postponement route. The backorder cost can be determined by getting the product of the probability of backorder, the demand per customer at a certain period that would be produced via Direct FG route and via Postponement route, and backorder cost per unit.

3.2 Constraints

The first set of major constraints refers to the proportion constraints. There are five proportions constraints used in the model. First would be the product type proportion. This ensures that the sum of the proportion of units to be produced via Direct FG and Postponement routes would be equal to one. The other four proportion constraints are the demand fulfillment proportions of the different facilities in the supply chain. These are the Cross dock demand fulfillment proportion, Customer demand fulfillment proportion, warehouse intermediate product demand proportion, and the warehouse raw material demand proportion. Their formulations are similar as follows: the summation of all proportions of all facilities that will deliver to the particular facility should be equal to one and this is done for all facilities. An example is shown in (4), which is the cross dock demand fulfillment proportion.

$$\sum_m PROP_{fmo}^{cross} = 1 \quad \forall f, o \quad (4)$$

The next major constraint would be the minimum order for raw materials to be replenished via direct replenishment. This constraint ensures that direct replenishment will only be used once the minimum order for raw materials is met as shown in (5).

$$DEM_{rm}^{raw-dir} + DEM_{rm}^{raw-post} \geq MIN_r^{ord} Y_{rm}^{mdir} NUM_{rm} \quad (5)$$

The service level constraint is based from the study of Kabling [5] and it will ensure minimum service level requirements of the customers will be met. This set of constraints requires to initially formulate the demand at each stage of the supply chain as well as the lead time components in the model that are dependent on demand since actual service level is the percentage of customer orders that arrive on time. The demand constraints control that material flow from supplier to customer. There are nine demand constraints needed in the model. As an example, the demand at the cross-dock is equal to the proportion of a customer order that would be produced directly into finished goods and be multiplied by either forecasted finished good demand or actual demand as shown in (6).

$$DEM_{foc}^{cross} = FDEMAND_{fc} \Pr op_{fc}^{dir} Y_{foc}^{cross} Y_{fc}^{short} + ADEMAND_{fc} \Pr op_{fc}^{dir} Y_{foc}^{cross} (1 - Y_{fc}^{short}) \quad \forall f, o, c \quad (6)$$

Another requirement for service level constraint is formulation of service level probabilities and probability of no delays which can be seen in (7). These equations were derived following the Jacobian Transformation. The probability of no delay would be formulated by integrating the demand rate from zero to the capacity of the vehicle or facility. An example is shown in (8).

$$\int_0^{ADUE_{cf} - TRAV_{wc}} n(Delay_{fwc}^{wveh}) d(Delay_{fwc}^{wveh}) = SERV_{fwc}^{wveh} \quad \forall f, w, c \quad (7)$$

$$\int_0^{VCAP_w^{war}} j(Total_w^{warcus}) dTotal_w^{warcus} = PDEL_{fw}^{wveh} \quad \forall f, w \quad (8)$$

Since the equations for the delay probabilities and the service levels for direct finished goods and postponement routes have been defined, the final service level constraints can already be derived. The service level for both the Direct FG route and the Postponement route should be greater than or equal to the service level requirement of a customer for a particular product, $SERV_{cf}$.

4. Model Validation and Sensitivity Analysis

The model was validated using General Algebraic Modeling System (GAMS). A relatively small network using hypothetical data was used in the validation. The system configuration used in the validation of the model is as follows: two manufacturing plants, two warehouses, one cross dock and two customers. The other factors are: two finished goods, three raw materials, one intermediate product and seven milk run sets. Furthermore, a sensitivity analysis was conducted using Response Surface Methodology (RSM).

Generally, the postponement production is more attractive when one of the demands is low and when there is high variation of demands. As shown in Figure 2, the proportion of postponement has an inverse relationship with mean demand values. The due dates are the same for both types of production method hence the use of postponement will be less attractive if demand increases since there is a higher chance to incur backorder. On the other hand, the use of direct production will have more time to produce finished goods since it makes use of a forecasted due which is longer than the actual due thus lower backorder cost will be incurred. While in Figure 3, another response surface for the proportion of demand fulfilled via postponement is shown. This figure shows that in a scenario where there is high demand variability for finished goods 1 and 2 it is more desirable to choose postponement. This behavior occurs because given that there is high variability the company is unsure and upon using direct production the company may incur high backorder cost or high holding cost.

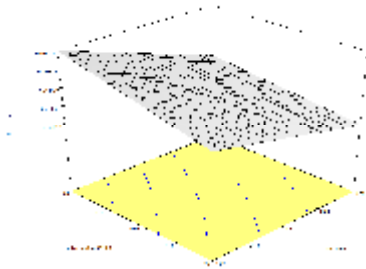


Figure 2: Proportion of Postponement (Mean Demands C1 and C2)

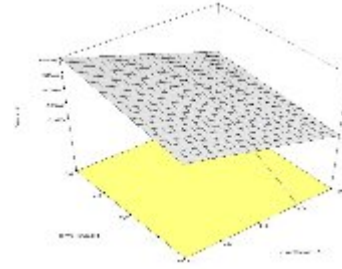


Figure 3: Proportion of Postponement (Var Demands F1 and F2)

Actual due dates and cost parameters affecting milk runs are two main factors which contribute on the likeliness of raw materials replenished via milk run. The number of raw materials to be milk run response surface is shown in Figure 4. The number of raw materials replenished via milk run is increased for both high and low actual due. In the former case, the number of milk runs will increase when the actual due is high since the manufacturing plant can conduct larger milk run sets making it much more cost efficient. While the number of milk runs will also increase when the actual due is low because it is much cheaper to conduct milk run rather than using direct replenishment because of higher probability to incur backorder costs. Figure 5 shows that given that there is high raw material cost and high direct replenished fixed cost it is more desirable to replenish raw materials via milk run. This behavior occurred due to the high holding cost. Hence, company would opt to order small batch sizes than large batch sizes which will be stocked at the end of the period. Also, upon having a high direct replenishment fixed cost a company may opt to choose milk runs due to cost effectiveness.

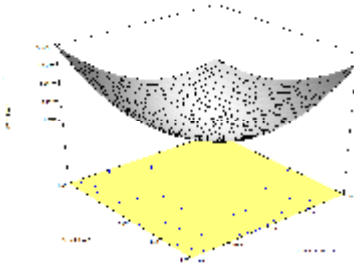


Figure 4: Raw Material Milk Run (Actual Due C1 and Actual Due C2)

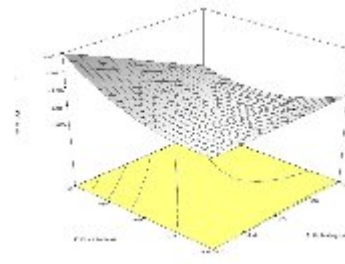


Figure 5: Raw Material Milk Run (Direct Fixed cost and RM Holding cost)

5. Conclusions and Recommendations

The study was able to integrate the concepts of lean manufacturing and agile manufacturing that can provide the lowest operating cost a supply chain can incur. The integration of the concepts of lean and agile manufacturing was achieved through the adoption of postponement along the supply chain. Moreover, the study has given a clearer insight on the different factors that would affect the implementation of milk run replenishment and postponement in a supply chain for lean facilities. The desirability of postponement was affected by the demand quantity and variability. There is an inverse relationship between the amount of goods to be postponed and demand. Milk run desirability is affected by the actual due dates of the customers, the RM holding costs and direct fixed costs.

A suggestion for further improvement of this study would be to include vehicle routing for milk runs. By considering vehicle routing the advantages of milk runs are fully considered since the distance travelled and the transportation costs will be minimized. For the warehouse, a decision can be included to determine whether the warehouse gets its supplies from the manufacturing plant through direct replenishment or from the suppliers through milk runs also milk runs can be considered for outbound logistics.

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