Key Components and Finished Products Inventory Optimization for a Multi-Echelon Assembly System

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ABSTRACT

A leading global information and communications technology solution company provides a broad range of telecom products across the world. Their finished products share commonality in key components, and, in most cases, are assembled after the customer orders are placed. Each finished product typically consists of a large number of key components, and the stockout of any components will cause delivery delays of customer orders. For these reasons, the optimal inventory policy of one component should be determined in conjunction with those of other components.

Currently the company uses business experience to manage the inventory across their supply chain network for all of the components and finished products. However, the increasing variety of products and business expansion raise difficulties in inventory management. The company wants to explore a systematic approach to optimizing inventory policies, assuring customer service level and minimizing total inventory cost.

This paper describes the use of SAS/OR® and SAS® inventory optimization technologies to model such a multi-echelon assembly system and optimize inventory policies for key components and finished products.

INTRODUCTION

A leading global information and communications technology solution company (referred to as "SHW" for confidentiality reasons) supplies a broad range of telecom products selling across the world. Their products range from the telecommunication infrastructure to personal communications facilities. There is a huge commonality in key components across many finished products. Customers usually place advance orders, but they might change or cancel orders before deliveries are made. In order to have a fast response to customer orders, components are assembled into sub-assemblies and stocked across the supply chain network.

Because of the uncertainty of customer orders and supply, SHW maintains a certain amount of inventory of key components, sub-assemblies, and finished products across the supply chain network. The stockout and the high inventory exist in the supply system at the same time. It is also hard for the company to tell whether there is room to decrease the inventory or to identify whether the current inventory is insufficient. SHW is looking for a scientific methodology to improve their current supply chain planning system and to suggest what to stock, where to stock and how much to.

In this paper, I discuss how to approach this business issue and optimize the inventory for SHW.

PROBLEM STATEMENT

SHW has one manufacturing plant, several warehouses, and regional distribution sites. The key components are assembled into sub-assemblies in the manufacturing plant. The sub-assemblies are shipped to the warehouses. The customer orders come with different package information. Each customer order specifies the required quantity of each item and the required delivery time. The items include the finished products and/or some sub-assemblies.

After the customer orders are received at regional distribution sites (RDSs), the sub-assemblies are assembled into finished products in the warehouses. Then the finished products are transported to the RDS to fulfill the customer orders at the required delivery time. To a large extent, this is an assemble-to-order system. However, the warehouses can deliver finished products to an RDS in advance in order to meet orders with a tight delivery schedule.

The objective of the research into the supply chain system is to minimize the delay in order delivery and maximize the inventory turnover ratio.

FINISHED PRODUCTS

Each type of finished product requires a unique selection of key components and sub-assemblies. Some of the components might be shared across several finished products. The time to assemble a finished product is short. The time to produce sub-assemblies, however, is substantial. Figure 1 shows an example of a finished product, DBBP530. It is made from the sub-assemblies MPT, BBP, BBI, and UTRP, and the key component DRRU Cable. Sub-assembly MPT is produced from key components OCXO, E1, and FE. There are two options for sub-assemblies BBI, which are 1.25G BBI and 2.5G BBI. Customers can choose either option when they order finished product DBBP530. This is also the case with sub-assembly UTRP. The assembly takes place in the warehouses. The production of MPT, BBP, BBI, and UTRP takes place in the manufacturing plant.
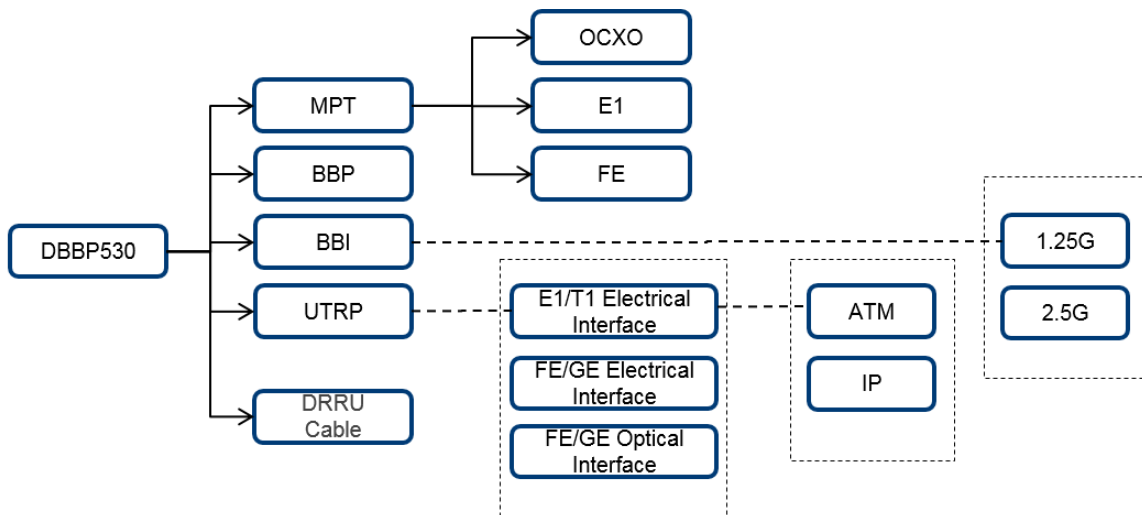

Figure 1. Example of Finished Product

ORDER FULFILLMENT

The customer orders can consist of finished products and sub-assemblies, which must be delivered on the required delivery date. Early delivery is not allowed. If products arrive at an RDS before they can be shipped to the customer sites, they must wait at the RDS.

SUPPLY CHAIN NETWORKS

Supply chain networks are classified based on the number of echelons (or levels) in their distribution network. Figure 2 illustrates the three-echelon supply chain network at SHW. Key components are acquired from external suppliers and stored in the plant and warehouses for the production and assembly processes. Sub-assemblies are produced in the manufacturing plant, and stocked across all echelons. It is worth pointing out that some sub-assemblies are open for ordering, so an RDS might carry an inventory of finished products as well as sub-assemblies. The supply lead times and production lead times at the plant are long. The assembly lead times at warehouses are relatively short.
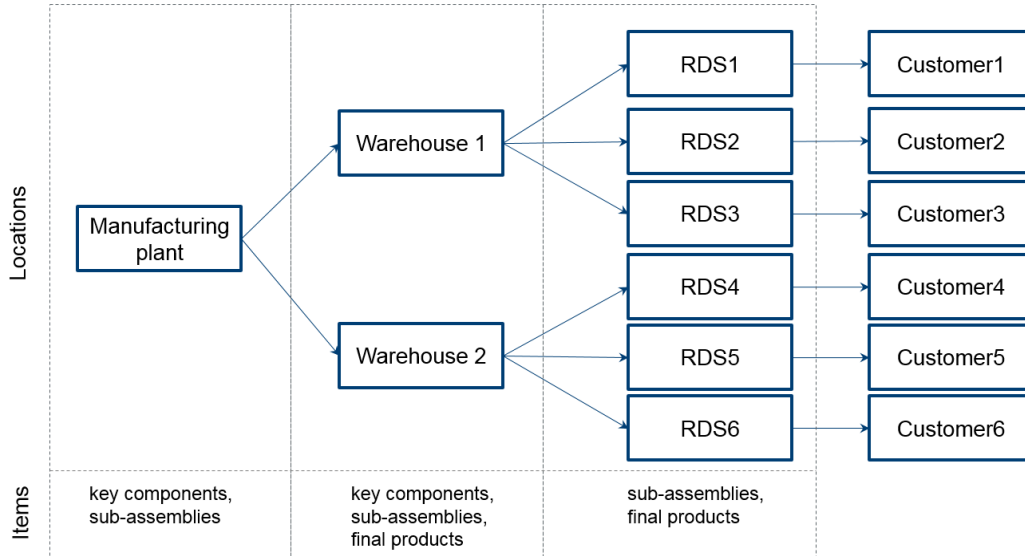
Figure 2. Supply Chain Network

In a typical assemble-to-order system, there is no need to carry inventory for finished products. The finished products are produced only when the orders are realized and shipped to customer after the production is completed. However, SHW needs to hold inventory for finished products for two reasons. The first reason is that the required delivery time is sometimes shorter than the production and assembly time. Therefore, SHW needs the finished products inventory to meet customer orders. Secondly, customers might modify their orders before the delivery date, which limits SHW's ability to respond to the modifications from production and assembly and thus requires SHW to use the finished products inventory to fulfill customer orders.

Currently business experience drives the inventory planning at SHW. In order to improve the inventory planning, it is necessary to answer these questions: Which key components, sub-assemblies, and finished products should be stocked in the supply chain network? Where should they be stocked? How much of each should be stocked?

SOLUTION APPROACH

The solution approach is depicted in Figure 3. The Demand Forecasts block provides the key input for inventory management. Service levels are optimized for each stock keeping unit (SKU) and location combination, from a global perspective. Then, we compute optimal inventory targets and order projections, based on the service-level settings determined in the previous step. With the order projections of sub-assemblies, the plant can optimize the production plan, and eventually generate the replenishment order suggestions for key components. The details are explained in the following sections.
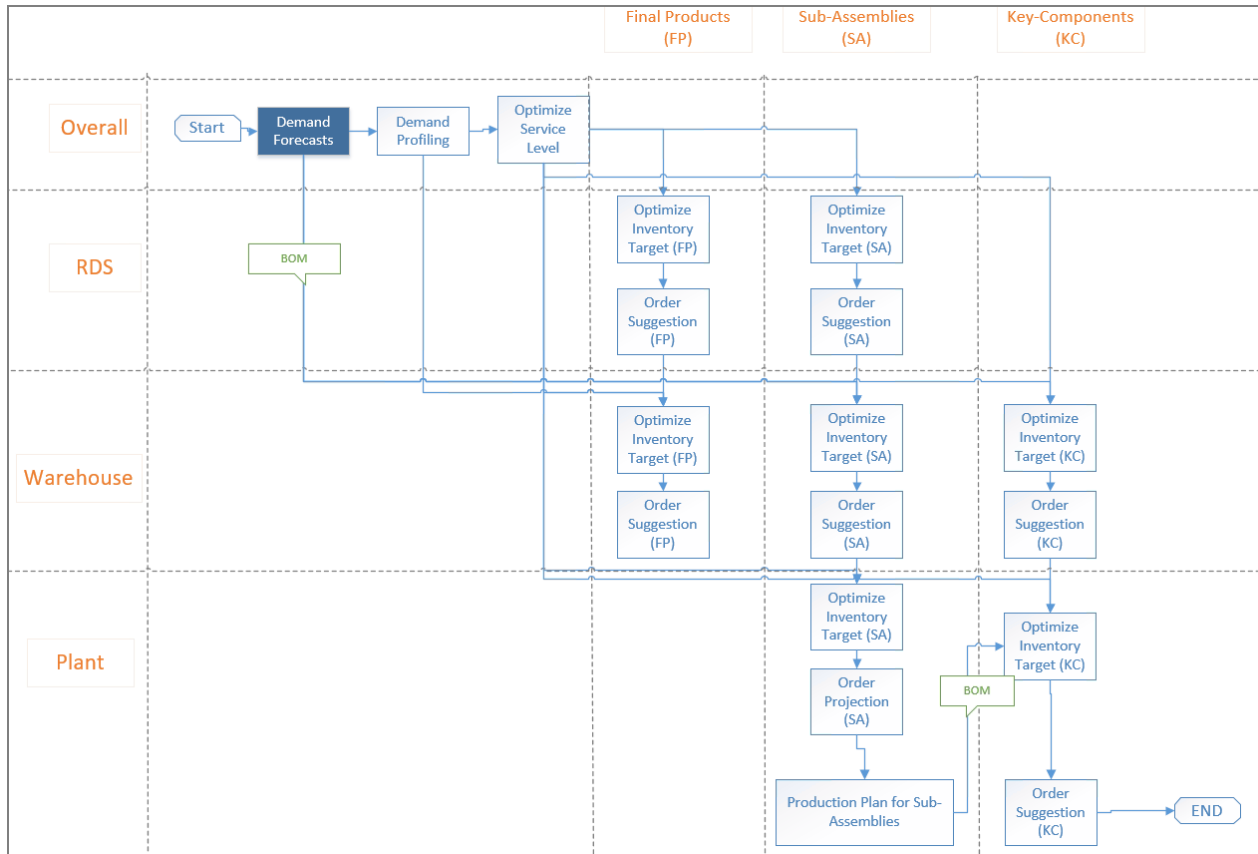
Figure 3. Overall Process Flow of Solution Approach

OPTIMIZE THE SERVICE LEVEL

As the first step, we determine the optimal service level for each SKU-location. The SKUs include key components, sub-assemblies, and finished products. The locations include the manufacturing plant, the warehouses, and the RDSs.

The service level is measured as the percent of orders fulfilled. If the customer order is delivered at the required delivery time, the customer order is fulfilled. Otherwise, the customer order is unfulfilled. Since service levels are set as long-term goals, the stationary demand is used for service-level optimization. The stationary demand is a long-term average demand of customer orders at the RDSs.
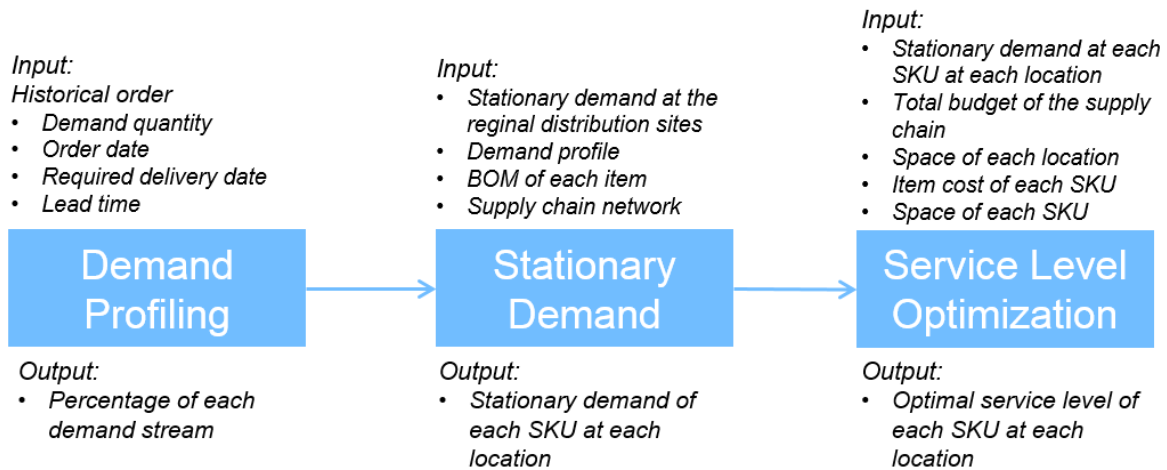
The order dates and required delivery dates are important. If the time difference between them is big enough, you will have enough time to assemble-to-order, or even to make-to-order. You need to carry inventory only to cover customer demand within the lead time. So first we must determine how much demand needs to be covered by inventory. A demand profile is produced using historical orders by comparing the time gap between order dates and required delivery dates with transportation time and assembly time. This profile partitions the demand into three different demand streams. The first demand stream is the order percentage to be fulfilled by the inventory at the RDSs, and the second stream is the order percentage to be fulfilled by the inventory at the warehouses. The last stream tells how much of the orders can be fulfilled by the assemble-to-order process at the warehouses.

In the RDSs, for finished products and sub-assemblies, you need to consider only the first stream of the stationary demand. The stationary demand of finished products at the warehouses is the aggregation of the stationary demand of their downstream RDSs. The stationary demand of sub-assemblies and key-components at the warehouse can be derived from the finished products and sub-assemblies quantity, considering of the bill of materials. However, for some types of sub-assemblies, the stationary demand includes internal demand from the finished products and external demand from customers directly. It is

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the same with the demand of key components at the manufacturing plant. Remember, all of the demand is within the lead time with respect to the SKU-location combination.

By knowing the stationary demand of each SKU-location combination, you can simulate the inventory target and the corresponding expected backlog for the different sets of service level, for example, by setting the service level from 80%, 81%,… to 99%. For each service-level setting, the MIRP procedure is applied to compute the expected backlog and inventory target. Then, the OPTMODEL procedure is used to determine the optimal service level and inventory target for each SKU-location combination with the objective of minimizing the total expected backlog across the supply network.

In order to optimize the service level for the entire supply chain, we use this close approximation to translate the multi-echelon problem to a single-echelon case. Figure 4 illustrates the process from demand profiling and a stationary demand calculation to service-level optimization, and enumerates the key input and output of each process.

Input:
Historical order
- Demand quantity
- Order date
- Required delivery date
- Lead time

Input:
- Stationary demand at the reginal distribution sites
- Demand profile
- BOM of each item
- Supply chain network

Input:
- Stationary demand at each SKU at each location
- Total budget of the supply chain
- Space of each location
- Item cost of each SKU
- Space of each SKU

Demand Profiling → **Stationary Demand** → **Service Level Optimization**

Output:
- Percentage of each demand stream

Output:
- Stationary demand of each SKU at each location

Output:
- Optimal service level of each SKU at each location

Figure 4. Process to Optimize the Service Level

Figure 5 is an example of statistics that show how many RDSs and how many warehouses hold the inventory for each SKU (the Item column), how much inventory is carried in the RDSs, the warehouses, and the manufacturing plant. Items 100, 200, 300, and 400 are finished products. Items 201 to 204 are sub-assemblies. Items 101 to 106 are key components. For some SKUs, like item 400 and item 203, it is not suggested to hold any inventory at the RDSs.

	Item	RDS_Count	RDS_Inventory	Warehouse_Count	Warehouse_Inventory	Plant_Inventory
1	100	6	8	1	9	.
2	200	10	945	2	631	.
3	300	8	17	1	27	.
4	400	.	.	2	219	.
5	201	9	15	2	15	21
6	202	.	.	.	.	.
7	203	.	.	2	318	232
8	204	7	264	2	228	316
9	101	.	.	2	631	945
10	102	.	.	2	234	424
11	103	.	.	2	356	218
12	104	.	.	2	27	34
13	105	.	.	2	781	736
14	106	.	.	2	58	76

Figure 5. Inventory Statistics

The service-level optimization determines whether it is necessary to carry inventory of finished products or sub-assemblies in each of the RDSs, and the service level for each SKU-location combination is also

optimized. If the inventory target is zero, it is unnecessary to carry inventory for the SKU-location combination. In this way, the supply chain network structure is constructed.

OPTIMIZE THE INVENTORY FOR FINISHED PRODUCTS

Finished products are carried in the RDSs and the warehouses. The supply chain network structure suggests the optimized SKU-RDS combinations and SKU-warehouse combinations. The optimal service level and the supply chain network structure are the main drivers to optimize the time-based inventory target for each finished products at the RDSs and warehouses.

Basically, the optimal inventory target is the sum of the safety stock and forecasted demand over lead time. The forecasted demand input is the first stream of demand within the RDSs' lead time. The forecasted demand input data includes the forecast mean and variance for each SKU-location combination. Safety stock represents the amount of inventory that is required to cover the uncertainty in the demand forecast, which is measured by the demand variance. Because customers can modify or cancel orders before they are delivered, the demand variance input is necessary for the time-based inventory target optimization.

For each finished product and RDS combination, the lead time is the sum of the average transportation time and the average assemble time. For each finished product and warehouse combination, the demand includes the internal demand from the replenishment orders of downstream RDSs and the external demand from the customer orders. The lead time is the average assemble time.

To determine the optimal time-based inventory target, you can use the MIRP procedure with the objective=OPTPOLICY. If the inventory position (includes the on-hand inventory and the pipeline inventory) is below the inventory target, the replenishment order of current period and order projections of future periods will be generated by setting the objective=ORDER_KPI in the MIRP procedure. Note that the optimal inventory target in this step might be different from the inventory target that was calculated during the optimization of the service level, and it varies across the time horizon due to the different forecasted demand.

OPTIMIZE THE INVENTORY FOR SUB-ASSEMBLIES

The sub-assemblies are produced in the manufacturing plant, and are then spread to warehouses and RDSs. This step optimizes the inventory of sub-assemblies in the RDSs, the warehouses, and the manufacturing plant. In the RDSs, the optimization logic and techniques are the same as for the inventory optimization of the finished products in the RDSs.

In the warehouses, the demand of sub-assemblies consists of two parts. One part is directly related to the customer orders and includes the internal demand of the replenishment orders from the downstream RDSs and the external demand of the customer orders (the second demand stream in the demand profile). The other part comes from all of the customer orders, expanded by the bill of materials.

In the manufacturing plant, the sub-assemblies are produced and stored. First, you need to calculate the inventory target for each sub-assemblies and generate the replenishment orders and future order projections. This is a typical use of the MIRP procedure.

With replenishment orders of sub-assemblies, you are ready to optimize the production plan, considering the availability of each type of resource, with the objective of optimizing the expected revenue.

OPTIMIZE THE INVENTORY FOR KEY COMPONENTS

SHW orders key components from external suppliers. The lead time for key components replenishment is long. It takes around 30 days to 90 days. Compared with the order lead time, the production time is quite short. The replenishment of sub-assemblies is accomplished by SHW's internal orders of sub-assemblies, which provide the required amount and the required date for each sub-assembly. The demand for key components is derived from the replenishment information and the bill of materials, and the demand time is simplified to the required sub-assembly date, considering the short production time.

The inventory of each type of key component is reviewed periodically. To avoid the unstable supply risk, SHW orders from more than one external supplier for some of the key components. The fixed ordering

cost and variable ordering cost are different for different suppliers. The longer lead time is applied into the inventory model to optimize the inventory policy. You can use the MIRP procedure to calculate the reorder and order-up-to levels for each period, and produce the order suggestions considering the inventory position. The order amount is allocated to different suppliers according to a best allocation plan, which leads to the least total inventory cost. To pick up the best allocation plan, the inventory cost, which consists of the fixed ordering cost, the variable ordering cost, and the holding cost, is first simulated for different allocation plans in the planning periods. Then, the mathematical optimization model is built with the objective of minimizing the total inventory cost.

CONCLUSION

This paper presents a solution approach that uses SAS/OR and SAS inventory optimization technologies to support a telecommunication technology company to optimize the inventory for finished products, sub-assemblies, and key components at different locations. For the first step, the demand is divided into three different steams. For the downstream locations, only the demand within the lead time is covered by the inventory. After that, the OPTMODEL procedure and the MIRP procedure are used to optimize the overall service level for each of the SKU and location combinations and to construct the supply chain network structure. Then, the inventory targets are optimized and replenishment order suggestions are generated for the finished products and sub-assemblies at all locations. The last step answers when, where, and how much to order for each key component.

CONTACT INFORMATION

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