MULTI-ECHELON INVENTORY OPTIMIZER
AN INTRODUCTION
Multi-Echelon Inventory Optimizer: An Introduction

Inventory in the Supply Chain

Inventory is commonly defined as the total amount of goods held in stock at a location. While it can include any and all kinds of goods, a supply chain practitioner is mostly interested in the inventory of products that are produced or packaged by the company and those components that are needed to make the above mentioned products; in that sense they can be divided into materials and components. There are three main categories of inventory based on the type of material.

1. Finished Goods Inventory
2. Intermediate or work in progress (WIP) inventory
3. Raw Material Inventory

For each of these material types, there are further two types of inventories: planned and unplanned (or at least excess). Planned inventories include:

- **Safety Stock** – Safety Stock is the inventory that businesses keep to account for the variability in the demand as well as in supply. Keeping this inventory allows a business to react (up to a certain extent) to an unexpected demand surge or a supply disturbance.

- **Cycle Stock** – Any business that has a set period (cycle) of time between subsequent replenishments would want to have enough inventories on hand to cover for the demand during this period. This portion of the inventory is called the cycle stock.

- **Anticipation Stock** – Business have to sometimes build inventories in anticipation of a peak demand period, or a future shutdown. This is often called anticipation stock

- **Pipeline or In-Transit Inventory** – In a business involving bulk transport, a large quantity of inventory may be tied up for days or weeks on a train or barge. This is called pipeline or in-transit inventory

- **Strategic Inventory** – Some businesses have to keep a certain amount of inventory to account for drastic changes to the sourcing or demand situation.

Figure 1 shows the different types of inventories in a supply chain.

Unplanned (or excess) inventories include inventories resulting from:

- Overly High Sales Plan
- Product Returns
// Inventory at Wrong Location

// Inventory in Wrong Package

// Off-Spec Material which can be Converted to Sellable Material

// Off-Spec Material which should be disposed of

// Experimental Product

// New Product Information

// Manufacturing Process – Some grades may be co-products or transition products and are produced to make products for which there is demand even though there is little or no demand for these products themselves.
Inventory management is the practice that deals with proper management of these inventories, both planned and unplanned. It is a very important field because the right amount of inventory can impact customer service in a positive way. The inventory components such as safety stocks can act as shock absorbers when the demand and/or supply are variable; in that sense they allow a business to run smoothly. Yet, too much inventory can be detrimental because it traps working capital and that has opportunity costs by way of missed opportunities. In this paper, we will primarily concern ourselves with the calculation of safety stocks, which can make up a substantial part of the total inventory at a company. We will discuss various ways companies have calculated safety stocks and also present a new holistic way of doing the calculations.

**Example Company**

Let us consider the case of Matt’s Ketchup Company (MKC) shown in Figure 2. The company makes tomato based products and sells it to consumers through company owned special retail stores of the same name as well as other retail stores. It has production facilities which ship to warehouses that in turn ship to the retail stores. Consumers mostly buy the product at the retail stores, but some part of the demand is also placed directly on the warehouses via internet orders. The flow of product is primarily left to right (with the exception of returns which we are going to ignore). This type of network is usually represented in transaction systems in a table called the Bill of Distribution (BOD).
Each plant in this company makes ketchup and other tomato based products. The production process uses raw materials such as tomato, vinegar, sugar and salt. Final products are then packaged and shipped to different warehouses, which then ship to the retail stores. This is shown in Figure 3. The distribution part of the network has been purposefully greyed out to highlight the Bill of Materials (BOM). The BOM has been simplified to show some but not all production. It is important to emphasize that the production process has multiple steps with Work-in-Process (WIP) inventories on the intermediate products.

Figure 3: Materials required at a plant to make ketchup.

As business has grown, MKC has put up plants in different countries across continents. Where possible, they have taken to getting local supply. In most cases the meet the customer demand in a region from the supply within the same region, but in some cases there are cross continent shipments as well (see Figure 4). In that sense, MKC is like many other companies with a global footprint.

The network footprint of MKC resembles any modern company of a significant size. For most industries, demand is global, and so is the supply. Customer base can be varied and demand (and command) different
service levels. Similarly, the supplier base can be very diverse and the supply itself could vary in quality, lead times etc. Given this backdrop, and the ever existing downwards pressure on inventory costs, it is critical that companies manage their inventories appropriately.

Figure 4: Global Network of plants and warehouses at Matt's Ketchup Company.

**Single-Echelon System**

Traditionally, a network such as the one described above was dealt with as a collection of single entities (or a single echelon). A single echelon system is where an individual node of material location combination is not affected by any other material-location. If a business was selling materials from a single location, then it would rightly be categorized as a single echelon system. However, inventory at many of these companies with networks that are truly multi-echelon is managed as a collection of single echelon systems. This means that each location would look at the demand and supply variability in isolation, and calculate the safety stock independent to the upstream or downstream location. Likewise, the Safety stocks on the raw materials would be calculated based on the variability in the consumption (demand) and supply for those materials. This is shown in Figure 5; each box therein represents a single echelon node. All taken together, they constitute the actual multi-echelon network at the company.

There are two main approaches in calculating the inventory targets when treating the network as a collection of single echelon nodes. The very naïve method is to use a set quantity of inventory as target for all products. This however is very quickly replaced in most companies by a formula based on days of supply coverage. This too can have variations. For example, the days of supply coverage can be based on historical usage, future usage, or an average of the two. Table 1 shows these options in increasing degrees of sophistication.
Figure 5: Individual nodes being treated as an independent single echelon entities.
Traditional approaches to this problem have taught us the following:

- The inventory goes up by a factor of square root of n as where n is the number of warehouses.

- As much as possible, one should keep inventories in the upper echelons to maximize flexibility and minimize total inventory costs. Under this strategy, we delay or postpone the differentiation in the product both by way of packaging or downstream products as well as location. For example, a business might keep its entire inventory at component (or bulk) level and only make the final product at the very last stage. Likewise, a business might decide to hold stockpiles of inventory at the central warehouse ready to be shipped to the forward warehouse at a moment’s notice. This strategy is called postponement. While this strategy does reduce the overall inventory cost in the single-echelon way of thinking, it assumes that the customer is willing to wait for the product. The fact, however, is that today’s marketplace places a premium on responsiveness and the postponement strategy is not ideal for responsiveness.

Most if not all traditional safety stock methodologies assume a single echelon network. Reality however is different in most companies. Most businesses operate through a multi-echelon distribution network (Plant/DC/Warehouse) as well as a manufacturing network (via production stages and BOM). The inventory levels at each of these levels have an impact on the required inventory at different levels. For example, a business might choose to push the entire inventory to the final distribution point which would mean a very fast reaction to a customer order (Make to Stock). And of course, there can be all range of situations in the middle based on the business and how demanding the customers are. Often, a company begins to think about optimizing the overall inventory footprint, and not just local calculations. When a company begins to ask these questions, they essentially are thinking of a multi-echelon inventory problem.
Multi-Echelon System

The simplest Multi-Echelon system is a serial system. It consists of multiple installations and each installation has at most one predecessor and one successor. While these serial linear systems can be found in both production and distribution environments, they are mainly of academic importance. Real life supply chain networks consist of linear, divergent and convergent subnetworks; they are also called “Generic systems”. Figure 6 shows an example of a generic Multi-Echelon Network.

Figure 6: A Generic Multi-Echelon Network.

The first step in Figure 6 is the manufacturing of the ketchup. This is an assembly type of operation with a convergent structure. Each plant will have this type of structure and the relevant data for this network is kept in Bill of Materials (BOM) and Bill of Routing (BOR) tables.

The second step is the distribution of the packed Ketchup bottles to the East, Central and West DC. This is a distribution operation with a divergent structure. The complete manufacturing and distribution operation has a generic network structure.
Multi-Echelon System
When networks such as the one above are treated holistically with an eye on reducing the overall inventory footprint, a lot of different forces come into play. For example, holding the inventory upstream (away from the customer) puts stress on the availability and the overall lead time variability for the customer delivery. This is typically not desired as no one wants to impact the customer service level. On the other hand, moving all the safety stock downstream (closest to the customer) would typically mean that the upstream nodes will have longer lead times. And what about locations that have no physical capacity to hold inventory? What about bottlenecks where we ideally do not starve the resource for work by running out of inventory in front of it.

When the network is treated holistically, taking into account the various factors that are a part of the network, it becomes a very complex calculation very quickly. A business is typically interested in finding the optimal (least cost) footprint of the inventory while still delivering the desired service level to the customer. In other words, the service level in in the internal nodes is open for negotiations, but the client facing service level is not negotiable.

Arkieva Multi-Echelon Inventory Optimization (MEIO)
Arkieva has designed its Multi Echelon Inventory Optimization (MEIO) module based on elaborate research in collaboration with Prof. Dr. Bram Desmet, Managing Director of Solventure (www.solventure.eu). Common Enterprise Resource Planning- (ERP) and the majority of Advanced Planning and Scheduling (APS) systems don’t include MEIO capabilities. The Arkieva MEIO module combines the advanced MEI capabilities with the data management, analytics, and reporting of the Arkieva supply chain suite. Clients are using this module to better optimize their inventory targets. Some clients then use these targets in their supply planning module to manage the business to these targets.

Some examples of benefits seen using the MEIO engine include:

/// 35% Reduction in Safety Stocks Investment at a Chemical Manufacturer

/// 30+% Reduction in Safety Stocks Investment at a Satellite TV Company

/// 30+% Reduction in Safety Stocks Investment at an Air Conditioning Manufacturer

Figure 7 shows how a business reduced their safety stock by re-positioning based on the recommendation of Arkieva MEIO.
The essential premise in the Arkieva MEIO module is to find the optimal configuration which minimizes the overall inventory cost while not compromising with the customer facing service level. It uses:

- **Appropriate Definition of Service Level (For Example, Cycle Service Level or Fill Rate Service Level)**
- **Customer expectations (For Example, Do the Customers Expect the Product Immediately, or Do They Provide Appropriate Order Lead Time)**
- **MTO or Otherwise Zero-Safety Stock Items**
- **Bottlenecks**
- **Strategic Materials (Where Presumably the Service Level is Higher)**
- **Business rules (for example, at least a certain number of demand data points before safety stock is calculated)**

In addition, it provides the capability to manage the calculations via managing the data inputs, ability to do what-ifs, and ability to evaluate the impact of different supply chain initiatives. For example, the business might want to evaluate the following investment options and the corresponding result on the safety stock.

- **Increase or Decrease Service Level by a Few Percentage Points**
- **Forecast Accuracy Improvement by 5%**
- **Supplier Lead Time reduction by 5%**
- **Internal Distribution Lead Time Reduction by 5%**
A business can use this type of analysis to understand which project would be the most beneficial from a return on investment point of view. Depending on the business parameters, different types of results are possible. These results are in line with what Aberdeen reported as part of their study of inventory management strategies as reported in Figure 8. This study further reported that only a small percentage of the companies are currently doing Multi Echelon Optimization.

There are a variety of forces that come into play in this calculation making the safety stock move upstream or downstream. Some of these forces are as follows:

// Long Lead times: As lead time get longer, the gap between customer order lead time (the time that the customer is willing to wait for the product) and the supply lead time typically increases. As a result, the longer the lead time, the greater the tendency to hold the safety stock closer to the customer.
Long order lead times can mitigate some of this effect as the customer’s willingness to wait means we do not need immediate ‘off the shelf’ availability. In effect, this is equivalent to reducing the supply lead time when it comes to the safety stock calculation.

Effect: Push Safety stocks downstream (close to the customer)

High Customer service levels: Higher the customer service level percentage, the lower the willingness to make customers wait for the product. Thus, higher service level requirements typically mean that the safety stocks should be positioned closer to the customer.

Effect: Push Safety stocks downstream (close to the customer)

Number of Echelons: Higher the number of echelons, the more exaggerated is the effect of risk pooling at the downstream locations. This effect is not very different from the effects of long lead times.

Effect: Push Safety stocks downstream (close to the customer)

Increasing Product Value: When downstream products have a lot more dollar value in them on a per unit basis, it becomes more expensive to hold the inventory in finished good form. As a result, the optimal results could very well be in one of the upstream echelons.

Effect: Tendency to move safety stocks upstream (away from the customer)

Inventory Carrying Cost as % of value (“Rent + Room + Risk“): This is similar in effect to the product value effect. If it is more expensive to hold inventories downstream, the optimal solution might be to move the inventory upstream away from the customer.

Effect: Tendency to move safety stocks upstream (away from the customer)

Constraints in Production or Warehouses: When certain materials are needed by a lot of other materials as part of the production process (based on bill of materials or BOM), or if a resource is a bottleneck resource, then the MEI calculation optimizes to position the inventory in such a way as to not starve the bottleneck. The net result could be that the inventory could be positioned in front of these bottlenecks.

Effect: Strategic positioning of safety stock in front of the bottleneck, typically moving it upstream.

Figure 9 summarizes the different forces at play and their impact on the MEI calculation.
Figure 9: Forces at play affecting MEI calculation.
Availability of Arkieva MEIO

For whom?
Manufacturers and distributors with Multi-Echelon production or distribution network.

What do you need?
- Data defined at the Material-Location level.
- Material Master.
- Location Master.
- At least 12 months of Demand history.
- Forecast History for period matching the demand history.
- Future Forecast.
- Bill of Materials (BOM). Not required if you are not a manufacturer.
- Bill of Distribution (BOD).
- MTO or zero safety stock materials.
- Bottleneck Material - Location Combinations.

Interested?
Interested in testing the added value of MEIO techniques for your network?
Contact sales@arkieva.com
Or find us at one of the locations indicated in the table below.

About the Author: Sujit Singh, CFPIM, CSCP, chief operating officer of Arkieva (www.arkieva.com), is responsible for managing the delivery of software and implementation services, customer relationships, and the day-to-day operations of the corporation.
ABOUT US

Since 1993, Arkieva tools have been used in more than 200 unique applications around the globe, and most of our clients leverage Arkieva software to support collaborative planning teams in North America, Europe, and in Asia.