Impact Analysis of Supply and Demand Variability on Inventory Deviation

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Abstract: The shortage or excess of components at a logistics centre is a combined outcome of the component level forecast provided to the suppliers by the manufacturing company and the actual supply of the component received from the supplier. The demand planning group shares the forecast with procurement group. The procurement group plans the supply based on the forecast and inventory information. However, the forecast can differ from the actual consumption. Similarly, the actual supply can be significantly different from the expected supply. Both supply and forecast variations have an impact on the inventory levels. However, it has been hard to point the mix of the supply and forecast variations on absolute scale and also it has been hard to tie the demand and supply variations on the inventory deviation. Inventory Deviation analysis technique helps the business find the demand and supply variability and also helps in measuring the individual impact on the inventory deviation. This technique is aimed to separate the performance of procurement of components from that of the performance of the forecast of the component. It has been applied to a global computer hardware manufacturers who primarily operates on a configure to order basis.

Keywords: Demand, Supply, Inventory, Variability, Supply Chain

I. Introduction

The problem that we shall discuss will be applicable to those manufacturing facilities that deal with warehousing of inventory. Vendor Managed Inventory (VMI) has been used to its hilt by a majority of the corporate worldwide. VMI lessens the burden of the manufacturer in terms of management of inventory [1], [2]. Some of the case studies have simulated the successful implementation of VMI [3]. The core of the VMI is the communication between the manufacturing unit anld the suppliers on a regular basis [4]. However, despite of the best communication processes, VMI provides ample challenges to deal with as we shall discuss in this document. Vendors warehouse inventory in Supplier Logistics Centers (SLCs) associated with such manufacturing facilities. There can be more than one SLC associated with every manufacturing facility. The Service Level Agreement (SLA) with the suppliers is that they will maintain a specific level of Inventory at the SLCs. The inventory level is measured in days i.e. given the current component usage, how many days will the inventory last? This unit of measurement is called Days of Sales in Inventory (DSI). Depending upon the different component utility & procurement rates, the suppliers are bound by contract to maintain a particular Target DSI quantity at the SLCs. Manufacturer pulls the required inventory components at the beginning of the production cycle (every few hours) from the SLC. This way, manufacturer is able to operate on a Just in Time (JIT) concept.

In the manufacturing setup, the Material Requirement Plan (MRP) is prepared by procurement team according to the Master Production Plan (MPP) prepared by the Demand Forecasting team. The MPP is an outcome of the Master Sales Plan (MSP) created by the finance team and MSP establishes the targets for the sales teams. Based on the forecasted sales of finished goods, the sale of the individual components is forecasted. This component level forecast is shared with the suppliers on a weekly basis. The team of buyers and buyer managers work with the suppliers to ensure that the suppliers are able to supply the required quantity. Due to the variations in the business assumptions and the customer preferences, the forecasts (both at the system level as well as at the component level) change from week to week. Since the future forecast for the next many months gets updated weekly and shared with the supplier each time it gets updated, the task for the supplier gets tougher. The suppliers operate with a specific procurement lead time window i.e. suppliers can manufacture according to the forecast provided to them “procurement lead time” before the actual week of component consumption. Once within the procurement lead time window, only a downward revised forecast signal can be effectively serviced by supplier. The supplier has very limited upside potential during the manufacturing lead time window. Suppliers work towards making quantity available as per promise.

It might happen that the actual demand is significantly different from the forecast that was available to the suppliers to act upon. The impact of such a dynamic scenario is such that:

- Either, there is a shortage of component.
- Or, there is an excess of a component.

In the first situation, the customer order gets held up. Each hardware system involves tens of components. Even if one component is short (out of stock), the order cannot be manufactured and as a result the customer experience takes a hit. It also leads to cancellation of orders and attrition in the customer base. In the second situation, manufacturer has to bear the cost of storage and the suppliers charges back the cost of capital held up due to sitting inventory. In some situations, it has been observed that the net percentage of components afflicted by one of the above 2 problems is as high as 40%. In computer hardware industry, there is a cost drop of approximately 0.5% per month. This implies that a $100M excess inventory would result in a loss of $1M every two months.

Computer hardware manufacturers operating on a configure to order basis have historically experimented with different models to maintain safety stock levels. Some of the safety stock models have been on similar lines as those covered in [5] & [6]. However, shortage of even single components leads to a buildup of backlog of platforms of similar types. Whenever the short component is available, all the similar type of backlogged platforms will get manufactured.

The dynamics on the supplier side is a bit different. While the supplier manufactures & ships according to the best forecast signal provided to the supplier, there are constraints of production capacity and shipping capacity that the suppliers have to look after. There can be significant challenges in fulfilling the available to promise quantity [7]. Also, most of the hardware manufacturer suppliers are known to be suppliers to other global computer hardware manufacturers like HP, Acer, Lenovo, Dell etc. Any indicated downside in future forecast, will motivate the suppliers to sell excess manufactured inventory to other competitors. In such cases, any later upward revision of forecast will not be satisfied by the suppliers. The proposed work can also be used to measure the magnitude of any bullwhip effect that might set in [8], [9].

II. The Problem Statement

Supply has been considered as a function of the forecast provided to the suppliers. The Forecast itself is a function of the business assumptions and the changing customer preferences. Since, the supply depends on the forecast signal provided to the supplier, how can supply variability be measured independent of forecast variability? Deviation of inventory from the required level depends on both the forecast deviation and supply deviation. During scenarios of shortage & excess, it becomes critical for the business to point out the mix of forecast deviation & the supply deviation. The challenge is to express the deviation in inventory as a function of the deviation in forecast and the deviation in supply. This will help the management analyze the root cause of deviations in inventory levels. Using the analysis and the insights, the management can introduce corrective actions in the demand forecasting process and the procurement process. Understanding the extent of supply deviations will help in pinpointing repeat offenders (under suppliers) in the supplier community. This will ultimately lead to the objective of storing the target level of inventory at the appropriate supplier logistic centers. Understanding the extent of forecast deviations will help in validating the different business assumptions considered to derive the forecasts. This will further strengthen the overall forecasting framework used by the manufacturer.

III. The Solution Framework

Deviation of Actual Inventory from Target is a result of two factors:
• Deviation in Actual Demand from Forecast
• Deviation in Actual Supply from Required Supply
Both of the above factors occur simultaneously in different proportions. There had not been any known system to break overall deviation between these two factors. The solutions required that the impact of demand variability & supply variability be measured on a common scale to assess the individual impact.

Measurements over every isolated week do not provide a proper insight since it is cumbersome to account for the shipment in transit. Hence, we measure the required parameters on every consecutive overlapping transit lead time window. For the frame of analysis, we measure and analyse the deviation in forecast and deviation in supply that hit inventory at the beginning of the specific week.
This analysis will be done for a specific component and for a specific manufacturing location.

Timeline

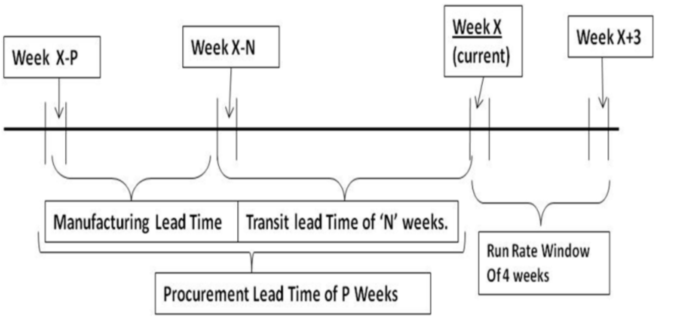

Figure 1. Explanation of the different segments of the timeline

All the calculations and measurements will be with respect to the beginning of a specific week 'X' as shown in Figure 1. The following points need to be observed:

- The aim is to ensure the target DSI (in days) at the beginning of week X. The target inventory quantity (Target DSI quantity) comes from the following equation.

$$Target\ Inventory\ quantity = T_D * FRR \qquad (1)$$

- Forecast Run Rate is the expected consumption per day for the particular component at the specified location as per the latest forecast scenario available. The Forecast Run Rate is the per day average of the forecast available over the 4 week window from Week X to Week 'X+3'. The forecast is available in weekly windows. Some of the computer hardware manufacturers work globally on a 5 day basis, we divide the sum of 4 week forecast by 20 days to arrive at the daily average.

- For the desired quantity to reach the SLC by Week X, it has to be shipped at least 'N' weeks prior to week X. This duration is referred as the transit lead time. It varies with the location of supplier, distance from the manufacturing location and the mode of shipment. A mix of modes of shipments might be used (e.g. (Sea + Rail) or (Air + Road) etc). However, N represents the actual time taken starting from the supplier to the delivery at the Supplier Logistic Centre (SLC). For the inventory to be received at beginning of week X, it has to be shipped by beginning of week X-N.

- The supplier has to start manufacturing the required quantity 'P' weeks before their expected delivery at the SLC. This duration is referred as the Procurement Lead Time window. This is required because the supplier needs some time to manufacture the required quantity of component before it can be shipped. Hence,

$$Manufacturing\ Lead\ Time = P - N\ weeks$$

For the inventory to be received at beginning of week X, the manufacturing has to ship by beginning of week X-N. At all points of time, the supplier is aware of the outstanding quantity of component inventory at the specific location. Also, in the beginning of each week, the suppliers receive the latest forecast signal for future 26 weeks. The supplier will start manufacturing according to the forecast received at beginning of week X-P. However, the forecast for week X will keep changing even after week X-P. It might happen that by week X, the forecast & the final actual demand are significantly different from the forecast that was given to the suppliers. Similarly, the supplier will ship after accounting the latest forecast signal received at beginning of week X-N.

Notation

P is the Procurement Lead time
N is the Transit Lead time
I_{X-P} is Inventory at the beginning of Week X-P
I_{X-N} is Inventory at the beginning of Week X-N
I_X is Inventory at the beginning of Week X
F_{X-P} is the 26 week forecast signal available at the beginning of week X-P
F_{X-N} is the 26 week forecast signal available at the beginning of week X-N

$$F_{X-P} = \begin{bmatrix} Forecast\ for\ Week\ X-P \\ \cdots \\ Forecast\ for\ Week\ (X-P+25) \end{bmatrix}$$

$$F_{X-N} = \begin{bmatrix} Forecast\ for\ Week\ X-N \\ \cdots \\ Forecast\ for\ Week\ (X-N+25) \end{bmatrix}$$

F^i_{X-P} is the forecast for week 'i' of forecast signal F_{X-P}
F^i_{X-N} is the forecast for week 'i' of forecast signal F_{X-N}
L_i is the Actual Usage (Sales) for the particular component during the week 'i'
S_i is the Actual Shipments received during week 'i'
T_D is the Target Days of Sales of Inventory (DSI)
O_P is the view of the order quantity at beginning of week X-P
O_N is the view of the order quantity at beginning of week X-N
O_S is the overall order quantity that should have got shipped over transit lead time window
FRR_P is the forecast run rate as per forecast F_{X-P}

$$Forecast\ Run\ Rate\ (FRR_P) = \left(\sum_{i=X}^{X+3} F^i_{X-P}\right) \Big/ 20 \qquad (2)$$

FRR_N is the forecast run rate as per forecast F_{X-N}

$$Forecast\ Run\ Rate\ (FRR_N) = \left(\sum_{i=X}^{X+3} F^i_{X-N}\right) \Big/ 20$$

IV. The Solution

Calculation of the Expected Shipments

For every transit lead time window of N weeks, the supplier will form a certain view of the order quantity. The task of the supplier is to at least fulfill the view of the order quantity. All the shipments that are expected from the beginning of Week X-N to the beginning of week X, have to be shipped by the supplier by the beginning of week X-N. The supplier would start shipping this quantity by week X-2N. However, by beginning of week X-N, the shipments would be sent so as to adjust according to the latest forecast available.

By the beginning of week X-P, the supplier would form a certain view of the order quantity required between week X-N & week X. The supplier would be manufacturing to fulfill the view of the order quantity that has been formed. The two primary components of this view of order quantity are:

- The quantity that is expected to be consumed over the transit lead time window i.e. from beginning of week X-N to beginning of week X. This quantity is
$$\sum_{i=X-N}^{X-1} F^i_{X-P}$$
- The quantity that is required to maintain Target DSI of inventory at beginning of week X is $T_D * FRR_P$ (from

(1)).

$$Target\ Quantity = \left(T_D \sum_{i=X}^{X+3} F_{X-P}^{i}\right) \Big/ 20 \qquad from\ (1)\&\ (2)$$

By week X-P, the view of the order quantity required from week X-N to Week X is based on the Forecast generated in week X- P (F_{X-P}).

$$\mathrm{O_P} = \sum_{i=X-N}^{X-1} F_{X-P}^{i} + \left(T_D \sum_{i=X}^{X+3} F_{X-P}^{i}\right) \Big/ 20 \qquad (3)$$

Similarly by week X-N, the supplier has a different view of order quantity required from week X-N to week X. O_N is based on the Forecast signal available by beginning of week X-N (F_{X-N}).
On similar reasoning as above:

$$\mathrm{O_N} = \sum_{i=X-N}^{X-1} F_{X-N}^{i} + \left(T_D \sum_{i=X}^{X+3} F_{X-N}^{i}\right) \Big/ 20 \qquad (4)$$

Overall, the supplier is expected to ship only the minimum of the expected order quantities. Suppliers will adjust their shipments such that they end up shipping the minimum of the two views of the order quantities. If the forecast signal was smaller during week X-P, then the supplier will manufacture and ship according to the lower forecast. If the forecast signal decreases by week X-N, then the supplier will like to keep the flexibility of retaining excess inventory at its own end. Supplier might send this excess inventory at some other location or send it later in time to same location or the supplier might even ship it to a different customer (since the suppliers of components to Dell, HP, Lenovo, Acer are approximately the same). O_S is the overall expected quantity that should have been shipped by the supplier by beginning of week $X - N$, then

$$O_S = \max(min(O_P\ , O_N) - I_{X-N}, 0) \qquad (5)$$

Any outstanding inventory at beginning of week X-N will automatically be adjusted by supplier in their shipments. The supplier need not ship this extra quantity since it is already there at the specific location.

Choice of Forecast Signal

Since the supplier adjusts shipments according to the lower view of order quantity visible, the same forecast (responsible for lower view of order quantity) should be used to measure the demand delta. If F_S is the forecast signal to be considered for demand delta calculations, then

$$F_S = \begin{cases} F_{X-P}\ if\ O_S = O_P - I_{X-N} \\ F_{X-N}\ if\ O_S = O_N - I_{X-N} \end{cases} \qquad (6)$$

Supply Delta & Demand Delta

The Difference between the “actual shipments (S)” & “expected shipments (O_S)” is the Delta in the supply (ΔS). Actual Shipments (S) received are logged in database systems in every company.

$$Supply\ Delta\ (\Delta S) = \sum_{i=X-N}^{X-1} S_i - O_S \qquad (7)$$

A positive ΔS implies that the supplier has shipped more quantity than should have been expected. Similarly, a negative ΔS implies that the supplier shipped less.

The difference between the cumulative Forecasts & the cumulative Sales over a given transit lead time window is the demand delta.

$$Demand\ Delta\ (\Delta F) = \sum_{i=X-N}^{X-1} F_S^{i} - \sum_{i=X-N}^{X-1} L_i \qquad (8)$$

A positive ΔF implies over-forecasting. Similarly, a negative ΔF implies an under-forecasting.

The Overall Analysis

Difference in the inventory quantity of two weeks will be a result of the actual shipments received and the actual sales of the component.

$$I_X = I_{X-N} + \sum_{i=X-N}^{X-1} S_i - \sum_{i=X-N}^{X-1} L_i \qquad (9)$$

Inventory at beginning of week X is the sum of inventory at beginning of week X-N, plus the sum of the shipments received from Week X-N to beginning of Week X , less the consumption from week X-N to beginning of week X. Now, we will establish that the deviation of inventory during Week X from the target inventory is a pure impact of supply delta (ΔS) & demand delta (ΔF).

Scenario No.1

View of order quantity drops from week X-P to week X-N, but not small enough to inhibit shipments.
Mathematically, scenario no. 1. can be explained as $O_S \neq 0$, $O_P > O_N > I_{X-N}$ and $F_S = F_{X-N}$. In such a scenario

$$\Delta S + \Delta F = \sum_{i=X-N}^{X-1} S_i - O_S + \sum_{i=X-N}^{X-1} F_S^i - \sum_{i=X-N}^{X-1} L_i \qquad From\ (7)\ \&\ (8)$$

$$= \sum_{i=X-N}^{X-1} S_i - (O_N - I_{X-N}) + \sum_{i=X-N}^{X-1} F_S^i - \sum_{i=X-N}^{X-1} L_i \qquad From\ (5)$$

$$= \sum_{i=X-N}^{X-1} S_i - \left(\sum_{i=X-N}^{X-1} F_{X-N}^i + \left(T_D \sum_{i=X}^{X+3} F_{X-N}^i \right) \Big/ 20 - I_{X-N} \right) + \sum_{i=X-N}^{X-1} F_{X-N}^i - \sum_{i=X-N}^{X-1} L_i \qquad From\ (4)$$

$$= \left(I_{X-N} + \sum_{i=X-N}^{X-1} S_i - \sum_{i=X-N}^{X-1} L_i \right) - \left(T_D \sum_{i=X}^{X+3} F_{X-N}^i \right) \Big/ 20$$

$$= I_X - \left(T_D \sum_{i=X}^{X+3} F_{X-N}^i \right) \Big/ 20 \qquad From\ (9)$$

$$= Current\ Inventory - Target\ Inventory \qquad (10)$$

Scenario No. 2

View of order quantity increases after week X-P and view of order quantity at week X-P is enough to cause shipments. Mathematically, scenario no. 2 can be put as $O_S \neq 0$, $O_N > O_P > I_{X-N}$ and $F_S = F_{X-P}$
Using the same methodology as shown in Case 1, we can arrive at the same results.

$$\Delta S + \Delta F = Current\ Inventory - Target\ Inventory$$

Scenario No. 3

One of the view of order quantity is small enough so that the supplier has no reason to send shipments ($O_S = 0$). Such scenarios satisfy the condition that $min(O_P, O_N) < I_{X-N}$. It implies that there is an overall excess inventory at the specific location. In such cases, the supplier cannot be expected to ship any more inventories to the specific location. In such cases, to achieve the target inventory, we will have to remove inventory from the supplier logistic centers. We shall keep such cases out of the preview of the current discussion.

V. Results & Analysis

For the sake of confidentiality, no private information of any manufacturer is shared here. We have taken inventory, sales & forecast figures hypothetically in Table 1. With the input of Table 1. and the application of all the equations discussed above, we receive Table 2. as the output. For this example P = 5, N = 3 and Target DSI = 10 days. Figure 2. shows that the same output as we derive in Table 2. Looking at Table 2. and Figure 2. one can make out that the supplier has consistently oversupplied inventory. Also, the forecast team has under forecasted for most of the period. At the beginning of Week 25, the current inventory is less than the target inventory. However, by beginning of week 26, the current inventory is significantly above target inventory. This is because of the significant increase in the shipments that arrive in week 25. By Week 27, the position of current inventory again deteriorates. This is due to the increase in the forecast delta. The gap between the forecast and the sales has further increased over the 3 week window of weeks 24, 25 & 26 compared to the transit window of weeks 23, 24 & 25.

Table 1.0

Input Data Elements

Week (X)	Current Inventory	Sales (L)	$_{X-N}^{X-1}\sum F_{X-P}$	$_{X-N}^{X-1}\sum F_{X-N}$	$_{X}^{X+3}\sum F_{X-P}$	$_{X}^{X+3}\sum F_{X-N}$	Shipments Received
Wk20	14,028	352	3,300	7,872	4,401	11,670	6,625
Wk21	20,301	3,880	4,560	5,725	4,529	13,858	212
Wk22	16,633	2,236	11,820	9,725	6,356	11,450	3,755
Wk23	18,152	3,420	12,725	10,561	8,356	7,450	352
Wk24	15,084	24,306	14,038	13,200	13,386	14,400	11,948
Wk25	2,726	7,465	12,038	11,715	18,734	13,523	20,641
Wk26	15,902	9,532	10,164	9,800	20,920	17,377	963
Wk27	7,333	5,319	10,164	16,026	24,076	16,026	1,208
Wk28	3,222	6,617	7,914	10,521	22,576	32,052	15,007
Wk29	11,612	7,590	7,914	13,932	18,078	18,723	921
Wk30	4,943	5,269	8,288	11,576	16,953	21,761	2,091
Wk31	1,765	14,629	9,000	11,576	15,828	23,152	13,849
Wk32	985	4,369	6,000	11,576	14,586	22,742	3,384

Table 2.

Result Data Set

Week (X)	O_P	O_N	O_S	F_S	Supply Delta	Demand Delta
Wk20	5,501	13,707	5,370	3,300	17,358	-5,530
Wk21	6,825	12,654	739	4,560	21,971	-3,934
Wk22	14,998	15,450	2,159	11,820	7,021	6,434
Wk23	16,903	14,286	258	10,561	10,334	4,093
Wk24	20,731	20,400	99	13,200	4,220	3,664
Wk25	21,405	18,477	1,844	11,715	14,212	-18,247
Wk26	20,624	18,489	337	9,800	32,605	-25,391
Wk27	22,202	24,039	7,118	10,164	26,434	-31,139
Wk28	19,202	26,547	16,476	7,914	6,336	-14,402
Wk29	16,953	23,294	1,051	7,914	16,127	-13,554
Wk30	16,765	22,457	9,432	8,288	7,705	-11,238
Wk31	16,914	23,152	13,692	-9,000	4,327	-10,476
Wk32	13,293	22,947	1,681	6,000	15,180	-21,488

Inventory position further deteriorates by end of week 27 (beginning of week 28). It is because of dual reasons. On one hand, we see that actual shipments received in week 27 have been corrected for the oversupply in the past. We observe that shipments in week 27 are much less than what was the expected shipment level for week 27. On the other hand, we see that the forecast delta does not improve as much as required. Sales over the weeks of 25, 26 & 27 have again outgrown the forecasts of consumption over weeks 25, 26 & 27 and the forecasts of target inventory for week 28.

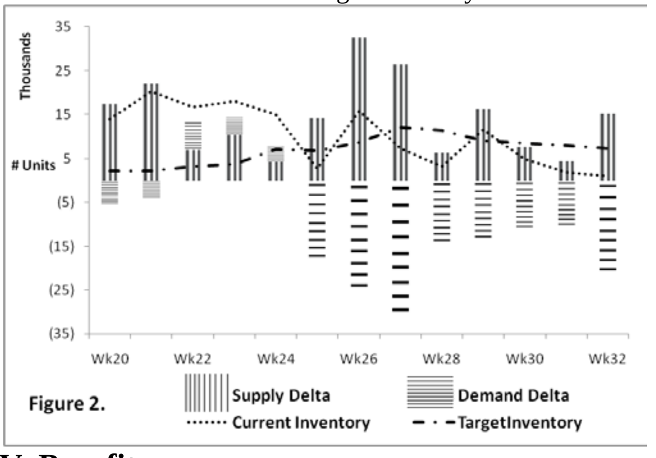

Figure 2.

V. Benefits

This analysis technique has been used by the management of Demand Forecasting and Procurement teams. Some teams have already started using the insights provided by this technique to do a postmortem analysis of inventory position. In the long run, this product is expected to help each hardware manufacturer in the following ways:

Feedback Loop This technique brings in a feedback loop in the procurement cycle. This cycle starts with the forecast team generating the component level forecasts. However, this cycle used to result in either a shortage or excess of inventory for a significant portion of the components. There was no comprehensive feedback loop mechanism available. The root cause analysis was not a well established process. With this product, the management gets to know the components and the locations that need to be monitored and improved.

Root Cause Drill Down This product is helping the management to understand the reason for the shortage or excess of a component at a particular location. If the fault is found to be with the forecast, the forecast mechanism for the particular component is evaluated. All the business assumptions that went in deriving the forecast at different points of time are re-evaluated. Similarly, if the reason is found to be supply, a robust process to ensure continuous and required supply can be worked upon by the company's management.

Retail This model can be applied to retail businesses, where we see similar scenarios of shortage and excess of finished goods. The Demand Supply Variability model will generate the required results for all such businesses.

VI. Conclusion

The Demand Supply Variability analysis approach has helped the businesses in tackling the key challenges of performance measurement and evaluation. As the concept sinks deeper with the organizations, this framework is expected to be replicated for other businesses. Some organizations are working towards developing a tracking mechanism by which the results over a period of time are analyzed. This can be expected to give birth to a process by which by which the forecast delta and the supply delta can be reduced simultaneously for each component at each location.

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