The "+Add" Model

A proposed Strategic Framework to Create Agile High Performance Aerospace and Defense Product Support Supply Chains
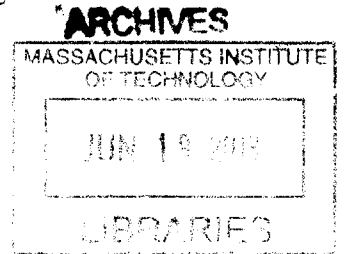
By

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Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

The U.S. Aerospace and Defense industry is a vital organ for national security and humanitarian disaster response as well as an economic powerhouse creating jobs and driving exports. News headlines often stop at the sale of complex, hi-tech and expensive defense systems short of capturing the critical aftersales support. However, it is the aftersales support that enables the mission to be accomplished. Without a well-functioning product support supply chain, even the most advanced fleet of fighter jets is rendered useless. This paper looks in-depth at such support supply chains within top industry companies. The investigation spans the current and desired states, and gaps the difference. It also establishes a visionary roadmap to get to the desired state and ensure optimum performance. The research proposes the "+Add Model", an easy to understand 5-level framework to achieve Global Optimization. The +Add Model acronyms stand for Aggregate Dynamic Derivatives, which are key elements in the framework. Aggregate refers to enabling a one integrated supply chain approach at the prime-integrator to benefit from economies of scale elements such as risk pooling and large discount buys. Dynamic refers to enabling a continuously improving supply chain through feedback loops making the supply chain agile. Derivatives refer to the realization that the supply chain is full of hidden derivatives (or levers). As in calculus, the derivative is a measure of how a function changes as its input changes. The +Add model identifies those main supply chain derivative functions and inputs, and then aims to fine-tune them to drive performance. By adopting the +Add Model a prime-integrator is able to improve demand forecast accuracy (Level-1), system planning lead times (Level-2) and increase collaboration with the supplier (Level-3). In turn, levels 1 through 3 enable significantly reduced supplier lead times (Level-4). Finally, as various programs apply the +Add Model approach, Aggregation (Level-5) provides additional benefits such as increased forecast accuracy, discount buys, and lower safety stock inventory through centralization. The +Add Model has a significant impact to the button line, analysis reveals substantial improvements to earnings, economic profit and cash flow while maximizing performance and reducing risk.

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1 Table of Contents

1. Introduction

The "+Add Model" Stands for Aggregate Dynamic Derivatives. It aims to add value to the aerospace and defense (A&D) industry by globally optimizing product support (after sale) supply chains through an easy to understand and deploy 5-level framework. It was developed as a proposed solution after researching current issues and identifying gaps in typical aerospace and defense product support supply chains.

1.1 Industry Basics

The Aerospace and Defense (A&D) industry is a vital organ for national security, humanitarian disaster response as well as an economic powerhouse. News headlines often stop at the sale of complex, hi-tech and expensive systems. However, it is the aftersales support that enables the mission to be accomplished. Without a well-functioning aftersales support supply chain even the most advanced fleet of fighter jets is rendered useless.

When out-of-control, A&D product support supply chains can spiral into cost overruns in the billions of dollars. The issue is only amplified by recent budgetary pressures. Consequently, the question becomes should programs be cut to keep with fiscal responsibility? But there is a better question to be asked, how can the programs be manage more effectively, thus realizing billions in cost savings.

This research aims to find the root cause of extended lead times and then develop a model to significantly reduce them, which in turn would enable significant cost reductions in weapon systems support while also improving performance. This model should be of primary interest to defense customers and industry players alike, as it will provide savings to the taxpayer without sacrificing warfighter programs. The benefits should be shared between the government

customer, prime integrators and their respective suppliers. As all three stakeholders realize additional gains, they will seek to further extend the collaboration and in turn the model will prove even more effective than initial engagement.

The research is primarily written to enable the support prime-integrator[1], as the lead, to achieve higher performance. However, it does require the support and collaboration of both customer and lower-tier suppliers. As can be seen from diagram in Figure 1, the prime-integrator is at the center of the supply chain, playing the vital role of "the link" between the customer and the supplier.

| Supplier | ⟷ | Prime Integrator | ⟷ | Defense Customer |

Figure 1: Supply Chain link

1.2   The Nature of the problem

It is perplexing how prime-integrators are able to successfully develop highly complex weapons systems, yet are sometimes unsuccessful executing the seemingly simple supply chains that support the product after the sale. Also puzzling is that the latest proven supply chains "buzz" initiatives such as forecast aggregation, supplier collaboration or risk pooling don't always solve the problem.

The objective of the research is first to unravel the mystery behind the poor performing supply chains, and why high-flying initiatives sometimes don't work. Then it paints the vision of an effective desired state supply chain. Finally, it provides an easy to understand a systematic 5-level process to achieve the goal.

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[1] Large prime contractor, often the OEMs, hired to execute the support contract with full responsibility for its flawless execution. Looked upon to provide technical oversight of sub-suppliers and supply chain innovation.

The research tackles the issue both qualitatively and quantitatively. This is because supply chains cannot be viewed only numerically; however analytics are an integral part. As mentioned by Prof. Jonathan Byrnes during supply chain case studies class at MIT[2], numbers provide "an anchor" to start the discussion and establish a baseline; however, the right quantitative answer may not be the most optimized.

1.3   The Proposed Solution

The "+Add" model is the culmination of the research. It was developed with the realization that for ideas and recommendations to be adopted, they need to be effectively communicated and easy to understand. To achieve agility and drive high-performance A&D product support supply chains, the model highlights the importance of the Agile Ring depicted in Figure 2 with its three main components: Aggregate Dynamic Derivatives.

Aggregate refers to enabling a one company prime-integrator approach to supply chain management. This is done through forecast aggregation of common parts through various programs, which in turn enables a more accurate unified forecast for supplier planning and taking advantage of economies of scale such as larger quantity discounted buys as well as lower safety stock through shared warehousing risk-pooling.

Dynamic refers to enabling agility by continuously improving the supply chain through feedback loops. This is achieved through focusing on critical data elements such as the demand forecast and lead time, tracking their forecast to actual, measuring the variance and then updating the input data, which in turn enables a more accurate output.

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[2] Fall 2013

Derivatives refers to the realization that the supply chain is full of hidden levers. As in calculus, the derivative is a measure of how a function changes as its input changes; the model identifies those main supply chain derivative functions and inputs, then aims to fine-tune them to drive performance. When unidentified, hidden derivatives make a "whack the mole" game out of supply chain improvements. Proactive supply chain managers often find themselves with unintended consequences from a previous solution they implemented. They then fix the latter only to find that the fix produced yet another unintended problem.
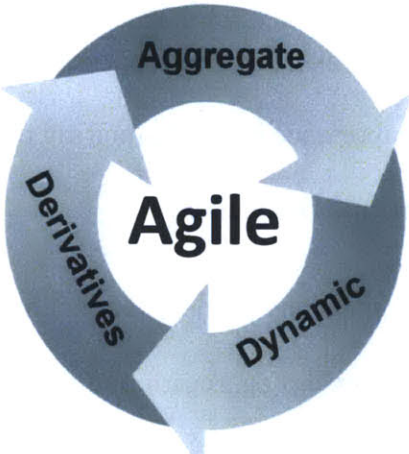

Figure 2: The Agile Ring

1.4 Numerical adjustments

For confidentiality reasons, the numbers published in this research financial or otherwise— are only representative. However, the recommendations derived from them provide a good indication of the current state and achieved desired state.

2   Literature Review

The aim of the research is to provide a framework that enables high performance aerospace and defense product-support supply chains. Such a goal is achieved only by considering the end-to-end supply chain and finding the global optimization. In addition, a series of correctly sequenced alignments need to occur—that is, aligning the supply chain with the business strategy, which in turn must be focused on the customer. This approach highlights the vitality and progress of the customer-supplier relationship. Figure 3, below, shows the relationship of the segments which ultimately drive higher earnings.

Figure 3: The path to driving higher earnings

2.1   Customer focused strategy

According to Monahan and Nardone (2007), the supply chain and the business strategy need to align. A prime-integrator in product support must not begin supply chain planning with internal costs but with the customer, then work outward from there. The prime-contractor has two end-customers. One is the warfighter, who is in harm's way' he or she seeks the promised

performance. The second is the taxpayer, who is looking for the government official to minimize costs. Thus, the strategy should be built around those two customer objectives -- performance and cost. The supply chain, in turn, should reflect them.

2.2 Supplier Management

In decades past, A&D companies such as Lockheed Martin, the Boeing Company and Raytheon have shifted from manufacturing to the outsourcing of components. Thus a prime-integrator is not able to successfully support the customer without having effective relationships with its suppliers. The heart of the +Add Model lays in effective supplier management; it is not about ordering the supplier one way or another, but rather about nurturing the relationship through collaboration. Dr. Jonathan Byrnes highlights the importance of this connection in his book *Islands of Profit in a Sea of Red Ink* (2010). According to Byrnes, a customer's supplier may go through the following five stages of maturity:

1. Stable
2. Reactive
3. Efficiently reactive
4. Efficient proactive
5. Revenue and margin driver

2.3 Basis of quantitative analysis

Having achieved the correct strategic alignment from being customer focused and effectively managing the partnership with suppliers next is tactical effectiveness which is partly achieved through numerical optimization. This was also the basis of quantifying the current state as well as evaluating the benefits of the desired state (proposed model).

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The research focuses on the inventory aspect of supply chain optimization. In product support, inventory is the difference between success and failure. Not having the right inventory means shortages and not meeting contractual obligations. Excess inventory could mean write-offs and financial loss. Basic inventory management notes that all things being equal, carrying lower inventory is better (Silver et al., 1998).

2.4 Inventory Target Levels

To achieve the required performance levels while minimizing cost, it is necessary to set the right Inventory Targets. A typical A&D inventory planning tool has a continuous review management system with a min-max review category. Thus the Inventory Target for a particular part comprises the Re-Order Point and Re-Order Quantity, which together make up a Order-Up-to (s,S) System (Silver 1998). The Re-Order Point is the forecast over the lead time plus safety stock (Silver et al., 1998), while the Re-Order Quantity is often the well-known Wilsons Economic Order Quantity (Silver et al., 1998).

2.5 Inventory Turns

Assuming the same performance levels can be maintained, the lower the Inventory Targets the better the company margins. Thus the desire to have as high as feasible inventory turns given the supply chain service requirements. According to Rivkin and Porter (1998), the competitive advantage Dell computer had over its competitors early on was the high inventory turns. The Inventory Turns formula can be defined as Cost of Goods Sold over average inventory (Weygandt et al., 1996).

2.6   Centralized Warehousing

Today, prime-integrators, for the same platform, typically have separate warehouses for different customer programs. Thus they have isolated safety stock for common parts, not taking advantage of any risk pooling between programs. According to Cooke (2010), the well-known toy maker Lego was able to reduce costs by 20% by reducing the number of distribution centers. This noted reduction is in line with the classic inventory theory that states the ratio of total relevant cost reduction in safety stock is equal to the square root of the ratio of the number of distribution location reductions (also known as the Square Root Rule).

3 Methods

Actively managed supply chain programs by prime-integrators within industry must be analyzed as a first step to building an effective framework for improving A&D product support supply chain performance,

Within the contractor, three product support supply chain programs were analyzed. The programs pertain to different customers in different regions of the world. Two of the programs have had major problems in the past and are considered turnarounds; the third was in its initial phase at the time of the analysis. They also differ somewhat in the type of service they provide. It was important to include different kinds of supply chain programs, both to see the common thread and also to provide a proposed solution that will satisfy a representation of different types of aerospace product support supply chains.

A full picture of the present situation was primarily painted through the following five methods:

1. Various data elements on 3,000 Items
2. Conducting interviews with key personnel
3. Attending and observing working meetings
4. Reviewing program performance charts
5. Studying functional procedures

The five different gathering methods were as if 5 different video cameras were recording a situation from different angles. As a result, a very powerful film of the current state, with its strength and weaknesses, was imprinted in the research.

3.1   Data Collection and analysis

The data collected and analyzed included two years of historical and current data related to individual parts (items) as well as overall program data. Table 1 shows the specific data elements collected, divided into two categories; specific part-level data and general program level data.

Table 1: Data Elements Collected

	Part level data included	Program level data included[3]
1.	Part Number	Total Inventory level Cost
2.	Part Description	Total Target Costs
3.	Monthly Forecast	Contracted Performance Metrics
4.	2-year Demand	Achieved performance
5.	Lead Time	Overall forecast accuracy
6.	Unit Cost	
7.	Quantity buy discount (some parts)	
8.	Associated Network (ABC)	
9.	Current Inventory	
10.	Forecast Accuracy	
11.	Current ROQ	
12.	Current ROP	

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[3] Not all information was available for all three programs considered

3.1.1   The Demand Forecast

Each weapons system support program produces its own forecast. In one Depot repair program, for example, the forecast is developed based on an end item induction schedule and associated piece part replacement rates, while for flight hour driven demand a casual forecast is used. Other programs utilize the exponential smoothing method. For the purposes of the research, determining the appropriate forecasting method was not a goal, thus the different forecasting methods were not compared to each other for best method.

For measuring the forecast accuracy, Weighted Mean Absolute Percent Error (WMAPE) metric with a one-year moving average is used. WMAPE is a good method in this context for two main reasons. The "absolute" aspect ensures that the over forecast is not cancelled by the under forecast, thus giving a true representation. The "Weighted" cost aspect gives the right emphasis. For example, inaccuracy in a ten cent part is not weighted the same way as a fifty thousand dollar part.

The WMAPE formula utilized, where A is the Actual Demand in dollars (demand x unit cost) and F is the Forecast in dollars (forecast x unit cost).

$$WMAPE = \frac{\sum \frac{|(A-F)|}{A} \, x \, 100 \, x \, A}{\sum A} \quad (1)$$

WMAPE Formula used in research

Mean Absolute Percent Error (MAPE), is another forecast accuracy method that is considered. MAPE is almost the same as WMAPE with the exception that WMAPE considers the unit cost of the part. The research revealed that for an overall program metric WMAPE is the better metric

as it is more representative; however, there is relevance for the demand forecaster to also track MAPE at an item level. The details on WMAPE and MAPE are provided in section 4.5

3.1.2 Inventory Position

The Inventory Position data collected and analyzed includes On-Hand Inventory, In transit Inventory, plus On-Order Inventory minus any potentially outstanding back orders. It is assumed that for all the weapon systems programs an IT system is already in use that tracks the inventory position and feeds it to the optimization tool on a nightly basis.
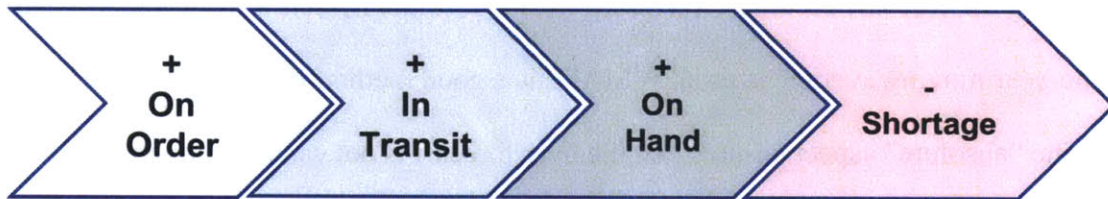
Figure 4: Inventory Position

3.1.3 Target Stock Level (TSL)

The TSL represents the future inventory. It is the plan the supply chain marches to. Thus functions such as the asset managers are putting order in the system to bring the inventory level to the TSL.

All programs are within the min-max, continuous review category; thus we have an Order-Up-to (s,S) System. In essence, the Target Stock Level is the summation of the Re-Order Point quantity (s) and the Re-Order Quantity. In its simplest form, the TSL formula can be states as:

$$TSL = ROQ + ROP \qquad (2)$$

Target Inventory Level (TSL) Formula

3.1.3.1 Re-Order Quantity (ROQ)

The Re-Order Quantity, Q, is the order quantity that will be requested from the supplier once the inventory position is equal or less than the reorder point. It also serves as the toggle to establish the rhythm of the supply chain. An optimized Q can be calculated through the traditional Economic Order Quantity formula (3) below. Where A is the fixed cost per order, D is the demand per year, v is the unit cost and r is the holding cost rate per year.

$$Q = \sqrt{\frac{2AD}{vr}} \qquad (3)$$

Optimized Order Quantity formula

Once an optimized Q is found, a consistent replenishment cycle time can be established through the following formula (4) below. Where T is the cycle time, D is the demand per year and Q is the Re-Order quantity.

$$T = \frac{Q}{D} \qquad (4)$$

Time cycle formula

There is a case for conversion from Q to T to keep a consistent flow in the supply chain. In addition, optimized Q* and T* can be established while taking into consideration discount buys from the supplier. See section 3.1.6 for additional information on discount buys.

The utilized order quantity does not necessarily have to be the EOQ. Order quantity may be based on an agreed upon number of month of forecast. However, the EOQ provides an optimized baseline.

3.1.3.2 Re-Order Point (ROP)

The Re-Order Point is comprised of two elements. Forecast over lead time, and safety stock. It can be represented by the following formula (Silver et al., 1998):

$$s = X_L + k\sigma \qquad (5)$$

Reorder Point Formula

The safety stock comprises the "σ" sigma, which is the demand variation over lead time. The "k" is the factor selected to achieve a desired fill rate or service level. In the aerospace and defense industry, while forecast has been relatively predictable (when compared to other industries such as the retail fashion or high-tech industry), lead times, on the other hand, have been problematically high. As can be noted from the Re-Order Point formula, lead times play a critical role on the size of the inventory. The research aims to find the root cause of extended lead times and then find a way to significantly reduce them.

3.1.4 Total Relevant Cost (TRC)

Minimizing total relevant cost is an important driver in supply chain planning; thus it is used throughout the research to compare alternatives. In most cases total relevant cost is defined as the holding cost, ordering cost and the purchase cost. Purchase cost is considered when the unit price is affected by the quantity buys.

$$TRC = \text{Holding Cost} + \text{Ordering Cost} + \text{Purchase Cost} \qquad (6)$$

Total Relevant Cost (TRC) Formula used

3.1.5 Centralized Warehouse Aggregation

The benefit of a centralized warehouse, that is shared across programs for common parts, is evaluated based on the following aggregation and risk pooling formula:

$$ROP = (L^e)\,(D) + (z)\,(STD)\,(\sqrt{L^e})^4 \qquad (7)$$

Multi-echelon Reorder Point Formula

Where L^e is echelon Lead Time, D is the average demand at the retailer, and STD is the standard deviation of demand at retailer. The above illustrated formula (7) is used in sections 4.7 and 4.8.5.3

3.1.6 Discount Buys

When calculating the benefits of a discount buy, the following formula is utilized:

$$TRC = \begin{cases} Dv_0 + \dfrac{AD}{Q} + \dfrac{v_0 rQ}{2} & 0 \le Q \le Q_b \\[3mm] Dv_0(1-d) + \dfrac{AD}{Q} + \dfrac{v_0(1-d)rQ}{2} & Q_b \le Q \end{cases} \qquad (8)$$

Discount buys Formulas and procedure

Where TRC is Total Relevant Cost, D is Demand, V_0 is price before discount, d is percent discount, r is the annual holding cost rate, Q is Order quantity and A is fixed Order cost.

Please refer to section 4.8.5.2 for specific example of the discount buys formula (8).

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[4] Design and Managing the Supply Chain, David Levi

3.2   Conducting interviews with key personnel

One-On-One interviews were conducted with personnel representing key functions in the supply chain. The wide-ranging interviews are a good source of different perspectives within the same company and supply chain. It was found that a logistics representative (employee of prime integrator) who is embedded with the warfighter (end customer) thinks very differently of the same situation than a supplier management person who works partly out of the supplier site (but who is also an employee of the prime integrator). It was important to conduct these interviews separately to have people speak their minds without strong personalities influencing the conversation. The separation also, to a certain extent, reduced groupthink. In addition, it revealed current frustrations.

The following roles were interviewed individually:

- Logistics Representatives (Customer perspective)
- Supply Chain Sr. Program Manager (Performance driven)
- Supply Chain Planning Function, Sr. Manager
- Asset Manager
- Demand Forecaster
- Supplier Management (Supplier perspective)

The format of the interviews varied depending on what was feasible and who was available. Some interviews were conducted face to face, others through telecom-WebEx. Some people were interviewed more than once (follow-ups after investigation suggested by them in the initial interview). Some interviews were longer than others. In all cases, it was important to let them speak freely and not hindering them even if bias they had a clear bias. Sometimes parties agreed, while other times they disagreed. The results of the interviews will be discussed in detail in

coming sections. Also the researcher highlighted the fact that they do not represent any particular group or bias and was simply after extracting their perspective.

Interviews were generally less structured and informal. This was to encourage participants to be themselves and share how they truly felt. There were three open ended questions that were asked:

1. How do you feel about the current state of the supply chain?

2. From your perspective where do you see the biggest issues in the supply chain?

3. What would you recommend be done?

The interviews evolved around the noted three questions, but it was more of discussion atmosphere then a Q&A session.

3.3 Attending and observing working meetings

Observing working meetings allowed for the collection of valuable information on the interactions between the various supply chain functions. It also gave a better understanding of the current issues and a feel for the daily battle rhythm of the operations. The following meetings were observed:

1. Quarterly Strategy Session

2. Monthly planning meeting

3. Bi-weekly collaboration meeting

4. Weekly forecasters tag up meeting

3.4   Reviewing program performance charts

A sample of program standard deck PowerPoint package charts were collected and examined. They provided insights into historical performance, recurring themes, as well as, what was important enough to track and status.

3.5   Studying functional procedures

Standard functional procedures were collected. Some were documented; others were gathered through the gathering methods mentioned previously in this section. They include key elements such as updating of lead times, measuring of forecast accuracy, and dealing with customer critical shortages. Current functional procedures aided pinpointing issues and identifying root cause.

4 Analysis and Results

In order to provide a model that unlocks agile higher performing A&D product support supply chains, the current state must be analyzed and the gap from it to a desired state identified Suggested improvements to bridge the gap should follow. Finally, the recommendations will be organized into an easy- to- communicate framework: the supply chain "+Add model".

4.1 Current Supply Chain Overview

From an overall overview picture, it is perplexing how a prime-integrator is able to design and bring to market complex systems such as fighter jets and Unmanned Air Vehicles (UAVs) yet have difficulty managing the corresponding support supply chains. Among the problems is excess inventory, as will be shown in this chapter

In the current A&D support supply chain, typically the prime-integrator signs up with the defense customer for a Performance Based Logistics Contract (PBL). PBLs have become popular over the last decade as customers have realized that it is much better to buy "performance outcomes" than "transactional" spares that don't guarantee the end goal. Thus a typical contract commits the prime-integrator to providing a certain fill rate or aircraft availability at a fixed price[5]. In turn, the customer commits to buying three to five years of service with the prime-integrator. The prime-integrator then buys from suppliers the right inventory targets based on the forecast, lead times and performance targets. In recent years prime-integrators have developed and acquired sophisticated tools to calculate optimized levels based on the latest inventory theories. A lot has been done to optimize based on the "given" supply chain design; however, not enough has been done to "change the given". Today, most

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[5] Contracts vary

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supply chains are not designed for global optimization, so the current optimizations, though using sophisticated tools with advanced algorithms, remain local within a specific section of the supply chain.

Another key finding is that the front-end of the supply chain changed drastically from transactional based buying to Performance Based Logistics (PBL), while other areas of the supply chain are still doing business the "old way", i.e., running with a transactional business mindset. The PBL needs to trickle to other segments of the supply chain. Figure 5 shows the current supply chain integration.
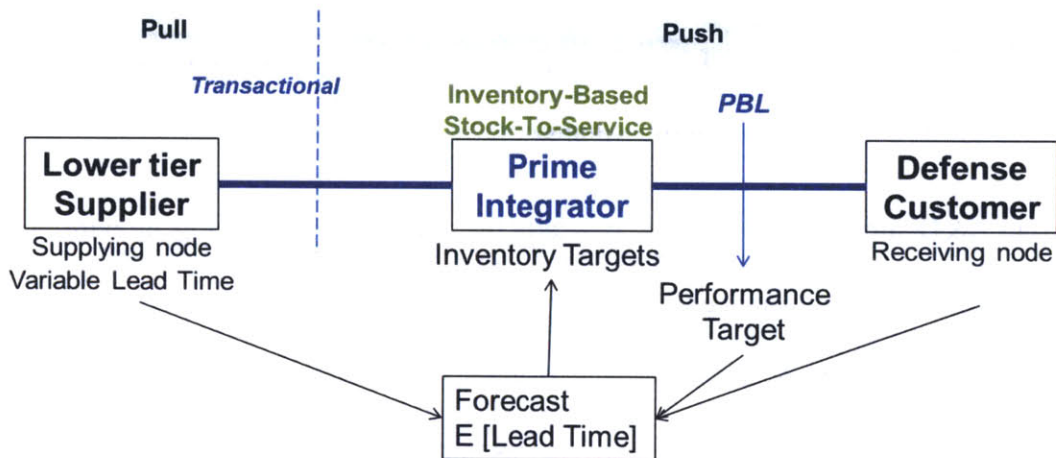

Figure 5: Current Supply Chain Integration

4.2 Make-To-Order vs. Stock-To-Service

A major issue identified in the current supply chain is that the prime integrator operates an inventory-based Push system, what the research coins as Stock-To-Service (STS), while the supplier operates a fully Make-To-Order (MTO) Pull System. This causes the prime integrator to hold the entire burden of the inventory to achieve customer contracted performance targets. Furthermore, the prime integrator bears all the risk in case of excess inventory, as well as

shortages. The lower tier suppliers should be viewed as possible areas to stock inventory. The inventory optimizer should be extended to include upstream supplier locations. Section 4.9.4 provides a detailed walkthrough how collaboration with the supplier drives the supplier to become more of Make-To-Stock (MTS).

4.3   Non-optimized padding

The graphs showed in Figure 6 and Figure 7, reveal that the customer as well as prime integrator personnel who are at the front end of the supply chain tend to provide forecasts that are bias towards being inflated with the mental model of "have a little more to ensure we have enough". This is revealed in the earlier month, prior to the over forecast issue being tackled. By separating the over forecasting error from the under forecasting error the bias is revealed. The interview with the logistics representative[6] revealed that in one case the forecast was used as means to adjust inventory.

In addition, suppliers, as well as, prime integrator staff members who are at the back end of the supply chain, tend to provide inflated lead times to ensure they meet their primary metric of meeting delivery dates.

As a result of having inflated forecasts and inflated lead times, the program overbuys inventory. Given all the excess spending, budgets become stringent and not enough money is left to buy what is actually needed; thus critical shortages become prevalent. The bias as well as the effect on the inventory are quantified and revealed in subsequent sections.

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[6] An employee of the prime-integrator that is co-located with the customer.

4.4   Effect of poor forecasting on lead times

According to an interview with supplier management, in the past top suppliers were provided with a best effort, but poor forecast. In one case the forecast was so highly inflated that it caused good-willing suppliers to over-produce and over-hire only to be left with excess product and having to let go as much as 40% of the workforce. This caused the supplier not to trust any given forecast by the prime integrator. As gathered from the interview with supplier management, the supplier mantra is now: "I will make it only when you commit to buying it". This has caused lead times to increase, however, according to supplier management; the supplier is willing to work with the prime integrator if they can prove they have an accurate forecast.

4.5   Causes of Inaccurate Demand Forecasts

The research has revealed five reasons for the inaccurate forecast as summarized in table 2. First, as mentioned above, the supply chain front-end has a bias towards inflating the forecast. Second, analyzing one program showed that the planning team trusts a defective IT demand feed, some demands types were being double count thus producing an inflated forecast. Yet another program had the opposite

Table 2: Cause of forecasting issues

	Root Cause Issue
1	General Errors due to lack of information at the time or bias
2	Demand System double counting or missing demands
3	"Clinching" of parts by shop floor mechanics due to historic shortages in an attempt to secure supplies.
4	Natural variation
5	External Forces (e.g. expected lower demand due to sequestration).

problem of not accounting for shortages, thus entrapping items into a catch-22 of not forecasting because they could not satisfy the demand. These two issues are hard to identify because the actual demand the forecast is measured against is in itself inaccurate. Furthermore, in some cases the forecasting function doesn't really have a good way to measure forecast accuracy. When using MAPE (Mean Absolute Percent Error), the overall forecast error is so high that forecasters are discouraged and feel uncomfortable sharing, while other forecasting teams bundle all the

overages with the underage, producing a "false" sense of security with a low forecast error, but in reality it is a meaningless metric.

Lastly, the supplier is provided with the program demand forecast. This is what the program expects to issue to the customer, which is different than the buying pattern from the supplier. The prime integrator buying pattern from the supplier does not only depend on the demand forecast, but also on the inventory policy (Reorder Point and Reorder Quantity) as well as current inventory levels. The demand forecast quantity and pattern is very different than the on order pattern and quantity from the supplier. Section 4.9.3.1 provides a walkthrough example of the difference between the buying plan and a demand forecast.

Through interviewing management, it was observed that in some cases upper management had not been fully informed of the dynamics of forecast accuracy. From intuition upper management deducted that forecast accuracy should be close to the performance requirement (thus above ninety percent). In one instance, a program forecaster was proud to present their forecast accuracy at 70% accuracy (Inverse of the 30% WMAPE), however, management saw 70% as an average "C" grade. Here also informing upper management of the mitigation of safety stock is important. As can be noted from the graph in figure 6, in June 2012 the Weighted Mean Absolute Percent Error (WMAPE) was 38%. The over-to-under forecast was at a ratio of 4:1. This indicates a significant bias towards over forecasting based on observations of forecast and actuals of one particular supply chain program, over a period of 16 month, for 6,926 parts. However, as a continuous improvement process was implemented that tracked and adjusted errors in the forecast, the bias was eliminated resulting in a significant improvement in the overall forecast accuracy, from a WMAPE 38% in June 2012 to 26% WMAPE recorded in February 2013. The improvement process is described in detail in section 4.9.1
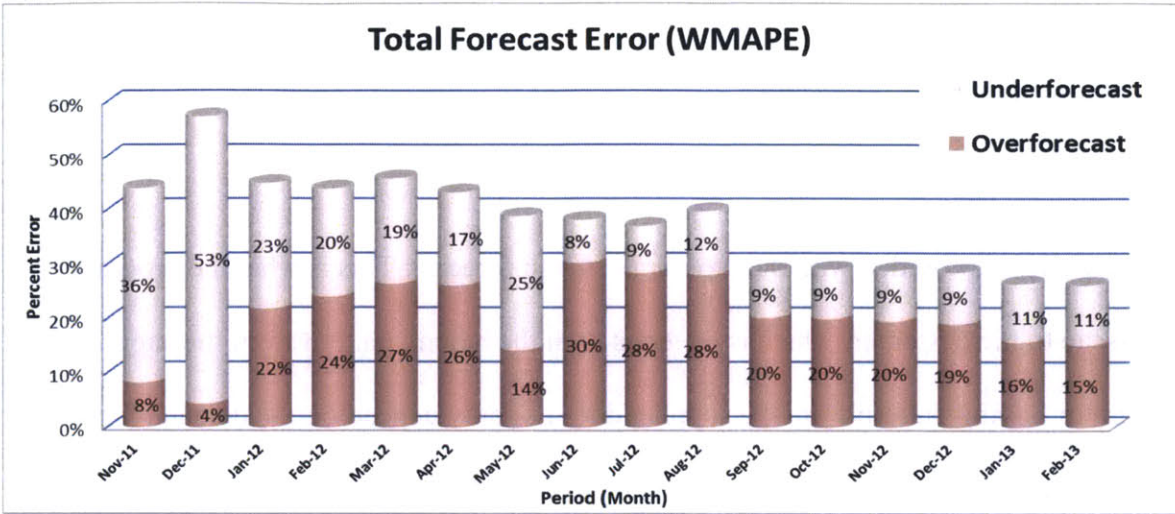
Figure 6: WMAPE monthly Error

From analyzing the data and tracking current inventory over the same period, it is revealed that the over forecasting error was causing significant excess inventory. This can be observed from the graph in figure 7, which shows the inventory ratio over the same period of time. The inflated forecast impact on the inventory was further magnified by the lead times. As the forecast improved, the target inventory went down significantly.
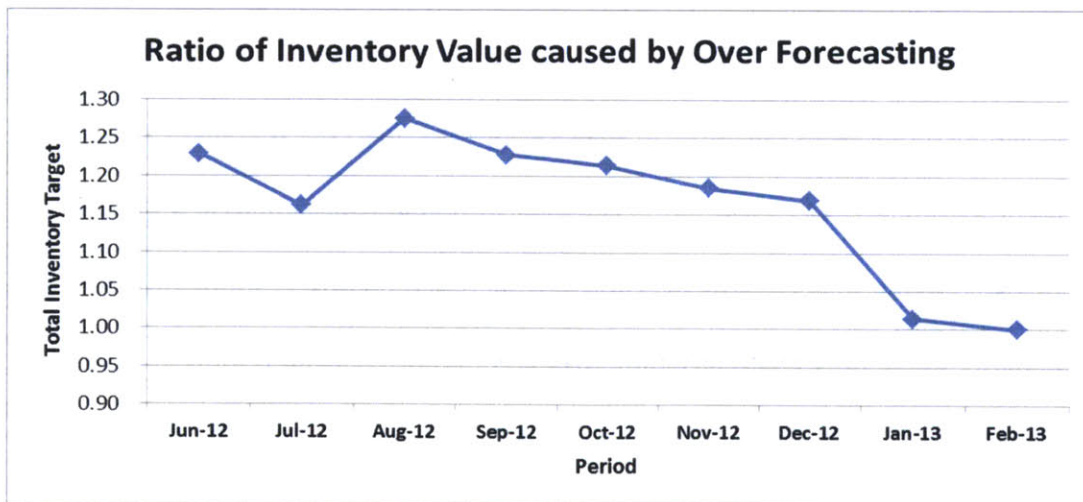

Figure 7: Monthly Inventory caused by over forecasting (ratio)

4.6 System Lead Time

Evidence from interviewing supplier management indicates that the lead times in the procurement system are used to plan the inventory in the supply chain. They are a direct input for setting up inventory targets and in turn determining the new-buy quantities. The lead times are manually entered by personnel in the buyer function based on a mix of: supplier provided future lead times[7], historical lead times, as well as, buyer discretional padding.

One interview with a program manager revealed that the performance of the buyer function is typically evaluated by on-time delivery. Thus company buyers tend to enter conservative[8] lead times, as it is easier to delay available products from the supplier, rather than expedite them. This was apparent in the comparison of system Lead Time to actual lead time of 33 parts. Table 3 shows a sample of 7 parts comparing system lead time to actual (in month). Furthermore, research artifacts indicate that depending on the person, buyers add one to three months of administrative time to the original lead time.

It is concluded from the interviews and meetings attended that perhaps some of the buyers and supplier management personnel do not fully realize the adverse impact of inflated lead times. An Excel model that illustrates the adverse financial effect of inflated lead times has been developed, this will help to change the mental model.

Table 3: System vs. actual Lead Time (in month)

Part	System LT	Actual Lead Time
a	21	19
b	31	25
c	30	21
d	22	13
e	23	22
f	15	19
g	18	17

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[7] Based on production capacity, raw material availability and other pipeline requests.
[8] i.e. inflated.

4.7 Aggregation initiative

In recent months, organization-wide efforts have been made to launch a forecast aggregation initiative. While aggregation improves forecast accuracy, logic tells us that without first achieving forecast and lead time accuracy, any attempt to aggregate the forecast for the purposes of sharing it with the supplier will not be as effective. One issue that might arise from not improving the forecast prior to aggregation is finger pointing. When issues arise in the aggregated forecast, if the forecast accuracy is not tracked at the program level, it will be hard to find the root cause.

4.8 Decentralized vs. centralized Warehousing

Today, each program manages an isolated warehouse. This causes each program to optimize safety stock separately, thus not taking advantage of risk pooling.

Currently, in a decentralized non-aggregated scenario, each program keeps its own safety stock. For a sample of common parts across the three programs analyzed, the total safety stock for those parts was $34 Million. In doing an analysis across three programs, risk pooling was found to bring down safety stock inventory by over 11%.

Figure 8: Decentralized warehouse safety stock impact scenario

The calculation for the analysis utilized the ReOrder Point formula described in the methods

section 3.1.5. A total count of 564 common parts were run through the specifically built

simulator in Excel. In the current state scenario each in program inventory was calculated

independently without consideration for a shared warehouse. On the other hand, for the desired

centralized scenario, a multi-echelon shared warehouse was assumed. For this scenario it was

assumed a 5 day lead time from the warehouse to the specific program depot. New buy lead time

stayed the same. A service level of 85% was assumed with a corresponding k of 1.04. The

benefits and recommendations of a centralized warehouse can be found in section 4.8.5.3.

Specific savings percentage will vary depending on service level, number of aggregated

locations and part characteristics.

4.9 Recommendations

To achieve agile high performance product support supply chains, a 5-level systematic approach is recommended. Each subsequent level has a dependent interaction with the prior one. This is because the success and meaningfulness of each level is partly dependent on successfully achieving the previous level.

The five levels of the "+Add Model" are:

1. Program-level Forecast Accuracy
2. System Lead Time Accuracy
3. New-Buy Plan Accuracy
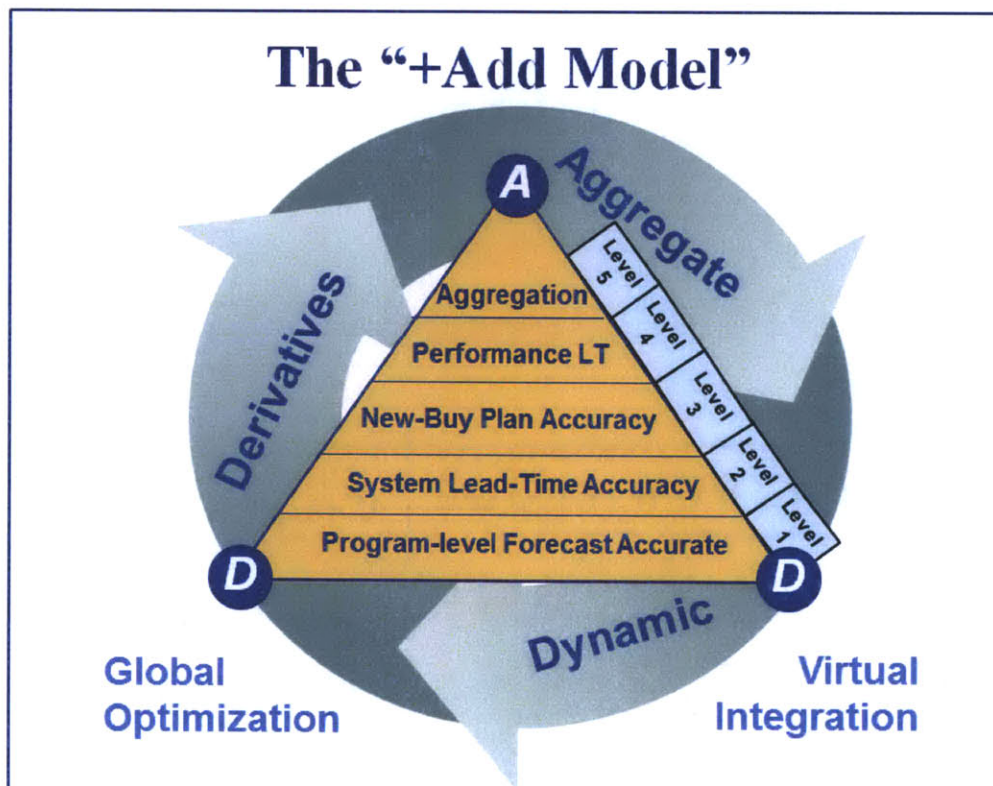4. Performance Lead Times
5. Aggregation

Figure 9: The "+Add Model"

To follow is an explanation of each level and how they depend and interact on one another.

Level 1: Program-level Forecast Accuracy

Forecast accuracy is a foundational step. It is the cornerstone of a high performance supply chain. Without a relatively accurate forecast there will be no significant benefit to aggregation. Also the prime integrator will not be able to produce a reliable buying plan for the supplier. There are three critical success factors to Level 1: using the right metric, establishing a feedback loop, and level setting senior management expectations.

4.9.1.1 *Using the right metric (WMAPE)*

When measuring, using the right measuring stick is imperative. It is recommended that a WMAPE[9] be used. Programs ought to aim for WMAPE error at or below 30%. The percentage is provided as an anchor; it is subject to adjustment based on the specific situation. The 30% target was deducted based on several extrapolations. For one, it was observed in one particular program that the timing of reaching the 30% WMAPE mark coincided with improved program performance and stability. Also it was apparent that shifting to other supply chain priorities was more beneficial than solely focusing on forecast accuracy to attain a couple more percentage points. It is detected that there will always be an element of randomness in the actual demand. Thus forecast accuracy will never be perfect. The effect of a small error will be limited to a few extra buys (holding inventory slightly longer) or buying a little less than optimal (ordering more frequently). If the right safety stock optimization is in place it will help in mitigating the risk of shortages.

It is important to note that along with the overall WMAPE number that is shared with management for the program, forecasters should track MAPE at the part level. This will help ensure program does not lose visibility of low cost parts.

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[9] See methods section

Additional implementation detail includes a 1-year moving average is recommended. Individual part WMAPE can be at maxed 200% error at 200%. If certain parts are missing significant demands they can be excluded from the overall number. In short, a common-sense filter can be put in place for the overall number.

4.9.1.2 Continuous Improvement Process

Without establishing a continuous improvement feedback loop, tracking the forecast accuracy is non-value add. A monthly process should be established to track the forecasted demand against actual issued demand; the cycle is depicted in Figure 10. Each month, the supply chain team should look at the top 10[10] parts by total forecast error dollar value, identify the root cause and then adjust the forecast if needed. The historical forecast should also be saved so it can be referred back to. Observed in one of the joint forecast development meetings with the customer[11] was a "pendulum-swing" of adjusting upward one time and then adjusting downward in the next review. This should be avoided. It is partly tackled by having a one-year moving average as well as referring back to the historical forecast.
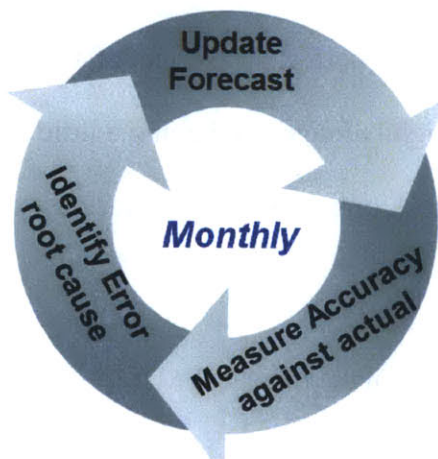

Figure 10: Forecasting Feedback loop process

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[10] Or any number they agree on, keeping in mind the 80/20 rule and focusing on the high hitters.
[11] Where the percentage of replacement piece parts to end item induction is determined

On a monthly basis the forecast accuracy overall metric should be shared with the program manager, as well as the functional supply chain manager. At a lower level a working monthly meeting should be established to work on the highest error parts. This meeting should have representation from all the functional areas, including forecasters, asset managers, spares engineers, and logistics representatives. During the meeting the root cause would be identified and a resolution plan would be put in place. Table 4 identifies the potential solutions of the top five issues that were found across the studied programs.

Table 4: Potential Solutions to Forecasting issues

	Root Cause Issue	Potential Solution
1	General Errors due to lack of information at the time or bias	Adjust future periods forecast
2	Demand System double counting or missing demands	Test IT feeds well Add/delete issue code
3	"Clinching" of parts by shop floor mechanics due to historic shortages in an attempt to secure supplies.	Shape shop behavior, Establish process to prevent above max expected demand pull per month
4	Natural variation	Expected. Mitigated through safety stock
5	External Forces (e.g. expected lower demand due to sequestration).	Scenario Planning, implement most-likely/lower risk scenario.

4.9.1.3 Level setting expectations

It is clear that the right expectation for forecast accuracy ought to be understood by all parties. The supply chain planning team should brief senior management on how a WMAPE error of 30%[12] is reasonable. In addition, forecasting personnel should inform management that safety stock is in place for the variance. After the program achieves an error less than 30% the focus should shift to other aspects of the supply chain, such as lead time reduction and manufacturing flexibility.

4.9.2 Level 2: System Lead Time Accuracy

Level 2 pertains to the system lead times used for planning the inventory targets. Having an accurate lead time in the optimization system allows for ordering parts from the supplier at the right time, for the reorder point is mainly the average forecast over lead time.

Similar to the forecast accuracy process outlined in Level 1, a continuous improvement feedback loop process needs to be established to measure the system lead time against actuals (the time between placing the order and when it arrives at the program dock). Figure 11 illustrates the this specific cycle.
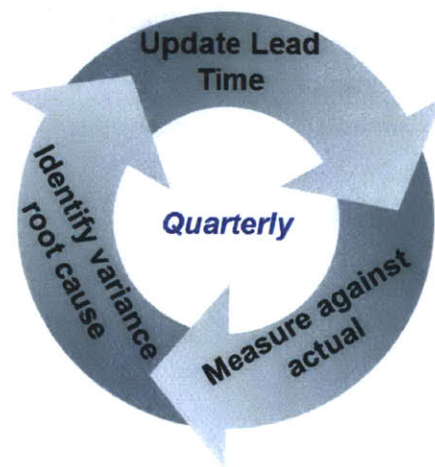

Figure 11: Lead Time Feedback loop

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[12] See section 4.8.1.1 on why 30% is recommended.

System lead times should be updated based on historical performance as well as input from supplier estimates if a foreseeable change is on the horizon. This feedback loop should be quarterly. When Level 4 is achieved (see section 4.8.4), then the system lead times may end up being lower than historical actuals as the supplier commits to reduced lead times in the future.

Lead times were investigated further for a subset of 32 parts. The system lead time was compared to actual lead time. Actual was calculated by subtracting order date from received date. For this particular subset of parts, it was found that overall current system lead times were padded by 5%. This padding in lead time caused an increase in target inventory in excess of 8%. The standard Reorder Point and Safety Stock formula was used in the inventory calculation as described in the methods section. This is because the Reorder Point has two elements of inventory impacted by lead time, one for the forecast over lead-time portion, and one for the safety stock portion. This 8% was equal to almost $900,000 for one program across only 32 parts. If this issue extends to the entire parts list of one program alone, the impact would certainly be in excess of ten million dollars. At the company level (across multiple programs) it may reach a hundred million dollars.
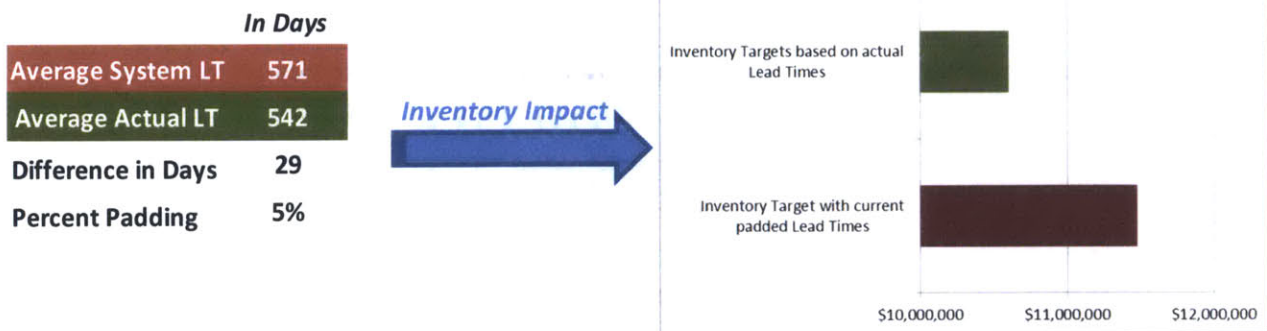

In Days	
Average System LT	571
Average Actual LT	542
Difference in Days	29
Percent Padding	5%

Figure 12: Lead Time Padding

4.9.3 Level 3: New-Buy Plan Accuracy

After ensuring that the product support supply chain is being planned and executed on an accurate forecast and lead time, Level 3 can be implemented. In Level 3, a long range buying plan that looks out several years is implemented. The buying plan should provide both the program and top suppliers with the expected quarterly purchases of the respective items. The buying plan should be first started for the top parts by extended cost[13] on the program. It was found that the top 120 parts (out of several thousands) accounted for 75% of the total cost. It is worth starting with the top 25 to 120 parts. On a quarterly basis, the suppliers will be provided with an updated buying plan, as well as the previous plan accuracy. This accuracy metric will increase the confidence of the supplier in the buying plan.

4.9.3.1 Elements of New-Buy Plan

There are four elements that go into the buying plan: lead time, demand forecast, current inventory position, as well as the inventory policy (ROP and ROQ). Any change to one of the 4-elements will affect the buying plan. This is critical because it will help identify the root cause of the variance in the plan to what actually was bought.
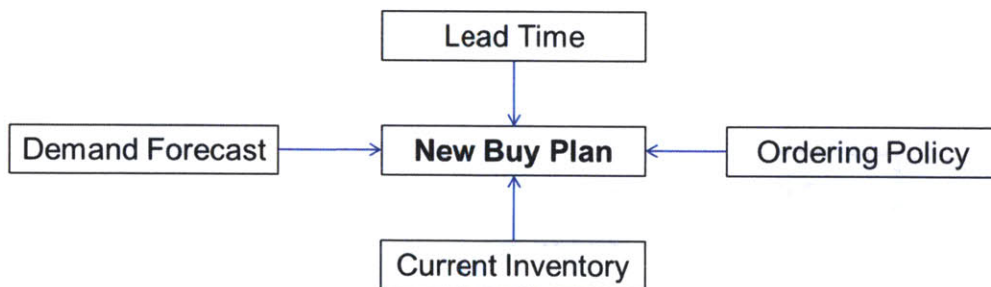

Figure 13: The 4 forces shaping the Buying

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[13] [Forecast x Unit Cost]

In the accompanying example in, figure 23, the supplier was given a buying plan that is equal to the demand forecast of 20 a month. This is because the actual issued-to-customer demand forecast was given directly to the supplier. The example shows that the supplier rushed into production and staging of finished goods inventory for delivery, but quickly realized that orders were not coming in as planned. What the prime integrator ought to provide is a true buying plan that takes into consideration the 100 units in stock, the reorder point of 50 and the reorder quantity of 70. This plan indicates that 80 parts will be ordered in third quarter, while another 80 will be ordered 15 month later.

Quarter	Demand Forecast	Starting Inventory	Ending Inventory	New Buy Plan
Year 1: Q1	20	100	80	
Year 1: Q2	20	80	60	
Year 1: Q3	20	60	40	80
Year 1: Q4	20	40	20	
Year 2: Q1	20	20	0	
Year 2: Q2	20	0	80	
Year 2: Q3	20	80	60	
Year 2: Q4	20	60	40	80

Quarterly Forecast	20
ROP	50
ROQ	70
Lead Time (month)	9

4.9.4   Level 4: High Performance Lead Times

Now that the program has achieved a relatively accurate demand forecast (Level 1), relatively accurate lead time (Level 2) and has a process to develop and track a buying plan (Level 3), it is ready for implementing the pivotal high performance lead time (Level 4).

Level 4 aims to significantly reduce lead times from the supplier and in turn inventory. As will be demonstrated in subsequent sections, the inventory reduction as a result of the lead time has a significant financial impact.

When the supplier is provided an accurate buying plan (Level 3), it is able to better plan for future demand. It was revealed from the supplier management interview that suppliers are willing to stage some inventory if they can trust the buying plan provided by the prime integrator.

In effect Level 4 aims to drive lead times down through making a paradigm shift in the supplier from Make-To-Order (MTO) to Make-To-Stock (MTS). Having the supplier increasingly stage inventory will bring down lead times, thus reducing both investment and risk, while increasing performance and agility.

The key is to arrive at a dynamic continuous improvement loop that produces confidence in planning and shapes supplier behavior towards staging stock and thus shaping a more globally optimized supply chain.
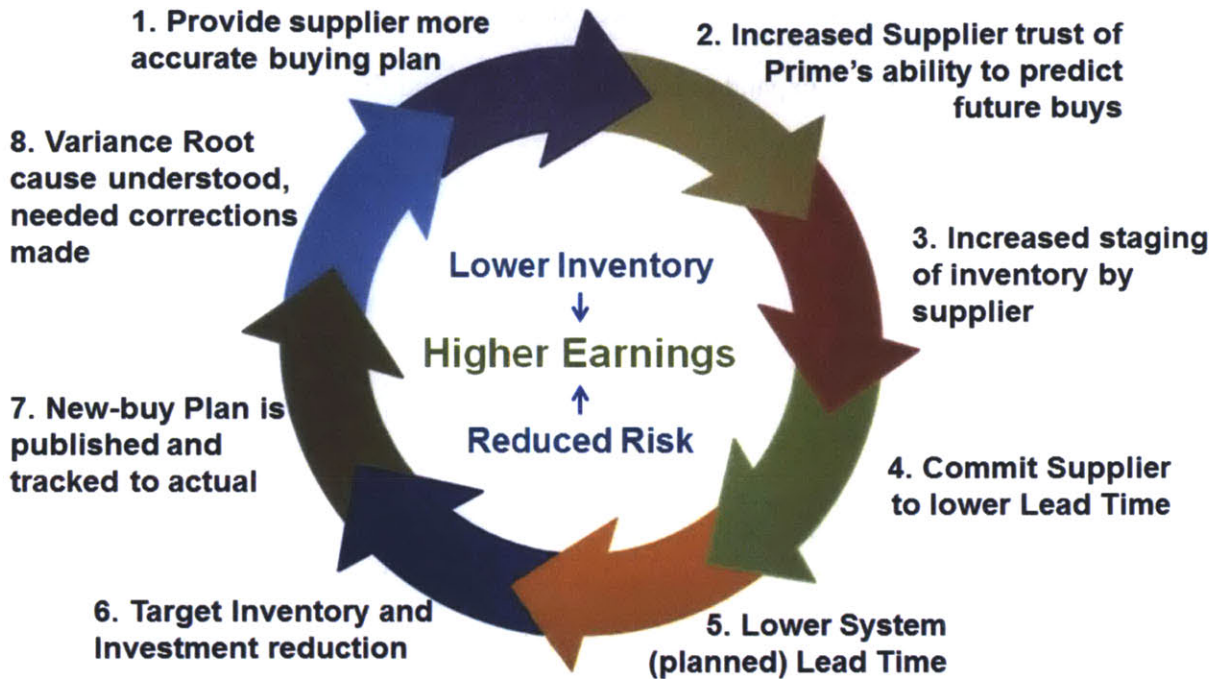
8-Step High Performance Dynamic Loop:

1. Provide supplier more accurate buying plan

2. Increased Supplier trust of Prime's ability to predict future buys

3. Increased staging of inventory by supplier

4. Commit Supplier to lower Lead Time

5. Lower System (planned) Lead Time

6. Target Inventory and Investment reduction

7. New-buy Plan is published and tracked to actual

8. Variance Root cause understood, needed corrections made

Lower Inventory ↓ **Higher Earnings** ↑ Reduced Risk

Figure 14: The 8-Step High Performance Lead Loop

4.9.4.1 *Performance Lead Times for top cost drivers*

In analyzing the data of a typical supply chain program at the prime integrator, we find that the top 25 parts by extended cost (Target Inventory x Unit Cost) account for almost 50% of the inventory cost. By contrast, a count of 25 parts represents only 1% of the 2,500
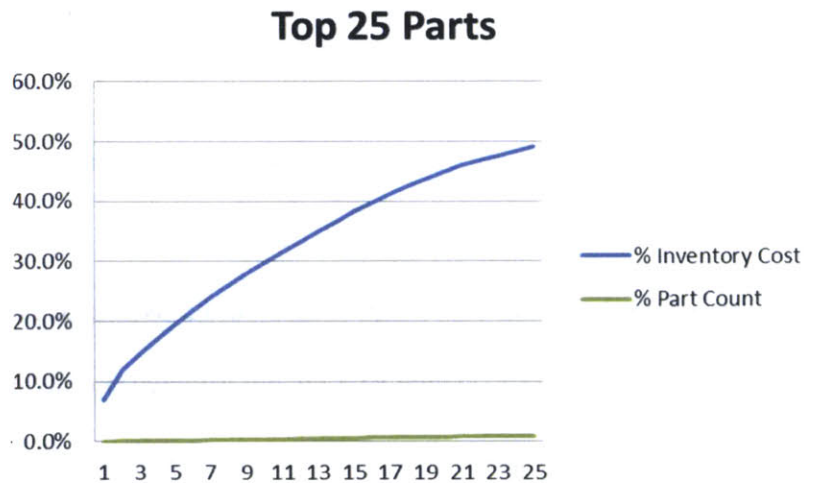

Top 25 Parts

— % Inventory Cost
— % Part Count

Figure 15: Graph of Count vs. Cost Percentage

42

parts analyzed.

Trying to manage and drive down the lead times of thousands of parts is unrealistic and unfruitful. Focusing on the high cost drivers is a key success factor. An initiative may start with the top 25 parts, and then quickly expand to include the top 50 and then the top 100 parts.

The accompanying table 6 shows the impact on inventory cost as the lead time of the top 25 parts is reduced.

Table 6: Impact of Lead Time Reduction

Reduction Scenario	Inventory ($M)	Reduction ($M)	Reduction (%)
Baseline	$ 117		
-5%	$ 115	$ (2)	-2%
-10%	$ 112	$ (5)	-4%
-15%	$ 109	$ (8)	-7%
-20%	$ 106	$ (11)	-9%
-25%	$ 103	$ (14)	-12%
-30%	$ 100	$ (17)	-15%
-35%	$ 97	$ (20)	-17%
-40%	$ 95	$ (22)	-19%
-45%	$ 92	$ (25)	-21%
-50%	$ 88	$ (29)	-25%

The results were reached through running 11 different iterations of the Inventory optimization calculations for each reduction scenario, plus the base case. In running the iteration, only the lead time was adjusted to create a controlled test, then the Target Stock Level (TSL) of each one of the top 25 parts was calculated. The TSL calculation involved adding the ReOrder Point (ROP) and ReOrder Quantity (ROQ). The formula used is as noted in the methods section 3.1.3 "Target Stock Level (TSL)". Since ROQ is not affected by the lead time, the related portion of the TSL was not affected. However the ROP was affected, both for the forecast over lead-time as well as the safety stock.

For example, through the 8-step process noted previously in Figure 14, if "performance lead-time" is derived for only the top 25 parts and a 30% reduction in lead time was achieved, the optimized inventory investment, for one program, would drop from $117 million to $100 million. This $17 million drop would equal a 15% cost for the entire program inventory. Similarly, at the 50% reduction level, the impact will be 25%. These cost savings are in addition to any cost savings realized at previous levels such as achieving high forecast accuracy (Level 1) and lead time accuracy (Level 2).

Inventory investment comes with a significant cost of capital. The reduction in inventory will improve earnings and overall affordability. It is also important to note that risk is reduced with the lower inventory, both the risk of shortage and the risk of excess, as the supply chain is now more agile.

Agile supply chains are able to quickly adapt to changing scenarios and align with customer needs. Certainly lower lead times, especially on the cost drivers, would enable an agile supply chain.

4.9.4.2   *Staging of raw materials*

One of the key success factors, as previously mentioned, is the transforming of the supplier from a Make-To-Order (MTO) to more of a Make-To-Stock (MTS) system. One of the specific actions the supplier can take is to buy raw materials in advance.

In analyzing a subset of 21 parts, related data was provided by supplier management for a major supplier. We find that the new-buy lead time given by the supplier is almost 70% driven by waiting on raw material from the second-tier, while the other 30% is production capacity. This is illustrated in Figure 16.

Meetings with supplier management revealed that if the supplier was given accurate buying projections by the prime, they would be willing to do buy in advance a portion of raw material. Given that the lead-times are mostly driven by the raw materials, staging of raw materials will enable the 50% reduction in lead time.

Figure 16: Lead Time breakdown pie chart
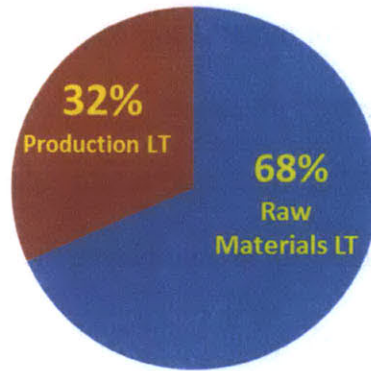
Furthermore, in evaluating the raw material unit cost of the provided 21 parts, raw material cost on average was found to be 14 cents on the dollar when compared to end item unit cost. This suggests that it is more cost effective to hold a portion of safety stock as raw material. Because of the size of the opportunity, the prime integrator should consider the option to guarantee the purchase of raw materials.

Table 7: Sample of raw material cost to finished goods

Finish Part	Raw Material Cost	Post Production Cost	Raw Material Percent Cost of post production
Part A	$ 250	$ 6,000	4%
Part B	$ 4,500	$ 22,000	20%
Part C	$ 1,800	$ 8,000	23%
Part D	$ 190	$ 6,000	3%
Part E	$ 450	$ 5,000	8%
Part F	$ 135	$ 830	16%

4.9.4.3 Creative contracting

Commonsense tells us, that even though the interview with supplier management reveals that the supplier is willing to work with the prime integrator to drive lead times given accurate planning, the supplier needs to be fully incentivized to achieve significant performance. Thus Contracting is an important tool in driving towards supply chain global optimization.

One possibility is to contract a guaranteed maximum lead time with the supplier. For example a service metric of 95%, the supplier shall provide part e within 70 days of a placed order. In turn the supplier can optimize their supply chain and raw material inventory to achieve this goal based on a given demand.

Another possibility is to implement option contracts. In this case the prime integrator can purchase the entire buying plan (level 3) as an option at a fraction of the cost (perhaps covering the raw material). This removes risk from the supplier and incentives them to act on the buying plan. Now as the prime integrator receives the ordered parts, they pay the exercise price.

Finally, depending on the situation a cost sharing/revenue sharing elements can be added to the contract. The idea is to drive mutual benefit, shape supplier behavior towards a more globally optimized supply chain as oppose to a sequential and segmented optimization.

4.9.5 Level 5: Aggregation

Level-5, Aggregation, sits at the top of the pyramid of initiatives. Now that the performance of the programs has been ensured, aggregation becomes a leap forward in supply chain planning. This allows for both the benefits of individual managed supply chains as well as the power of integration and economies of scale. The first step is to implement aggregation into the forecasting process and new buy supplier plan. This allows of benefits such as a better forecast accuracy and volume discount buys.

4.9.5.1 *Forecast-Buying Plan aggregation*

The research shows the value of developing an aggregation process. On a monthly basis, programs will send the forecast to the centralized forecasting staff along with their respective WMAPE score. In turn, the centralized forecasting staff will update an aggregated buying plan. The function will then on a quarterly basis provide the updated buying plan to the supplier[14].

It is important that the programs are still held accountable for their own forecast accuracy and that issues in the aggregated forecast can be pinpointed to a specific program. Along with providing the forecast, the programs need to provide the other elements such as the inventory levels and inventory policy. Initially when this process is done through excel it will have to be limited to a smaller subset of parts. However, once value is recognized it can be automated through proper databases and IT feeds.

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[14] Programs no longer need to provide individual buying plans to the supplier

4.9.5.2 Discount Buys

Discount buys will be of tremendous benefit at the aggregation level. The prime-integrator will now take advantage of tremendous economies of scale in bundling purchase orders together, something that is not taken advantage of today.

Table 8 shows the possible discounts for large buys as provided by top suppliers for a sample of parts, while the forecasted demands were pulled from three different programs. Programs don't currently take full advantage of the discounts. This is because simply using the EOQ formula based on the unit cost is not enough to find optimal buying points. Instead the total relevant cost needs to be evaluated, and the quantity that minimizes the total relevant cost should be picked. This can be done without aggregating the expected demand across the programs.

Table 8: Large Quantity Discount buys

	Unit Cost based on quantity Ordered						Forecasted Demand			
	Qty. 1-9	Qty. 10-24	Qty. 25-49	Qty. 50-74	Qty. 75-149	Qty. 150-300	Program A	Program B	Program C	Aggregated
Part A	$4,492	$3,293	$2,648	$2,456	$2,441	$2,370	325	98	88	511
Part B	$13,560	$10,265	$9,479	$8,784	$8,784	$8,784	44	13	12	69
Part C	$1,801	$1,322	$1,088	$786	$786	$786	23	7	6	36
Part D	$3,301	$1,960	$983	$646	$558	$499	446	134	121	701
Part E	$333	$175	$76	$54	$54	$54	440	132	119	691

However, aggregating the demand makes the case for taking advantage of further discounts, as now the larger quantities will be shared across programs and not eating up holding cost.

For example, for part B, if all the programs would aggregate the yearly buys, the total would be $606,096 [69 x $8,784[15]]. By contrast, in buying separately the yearly quantities Program A would be paying $417,076, program B $133,445 and program C $123,180, a total of $ $673,701 or a savings of over $67,000.

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[15] Discounted price offered by supplier for quantities ranging from 50 to 74.

4.9.5.3 Centralized Warehousing

With an aggregate forecast a centralized warehouse can be established with the right inventory levels for the common parts across programs. There will be no significant additional transportation costs, as for export reasons, parts need to go through a specific location today before they are shipped internationally. This location can be developed into a warehouse, with some inventory held back rather than push forward to the specific program location. This will reduce safety stock as risk pooling will take effect. Instances of inventory planning tool at the program level need to be linked with a centralized instance. The programs planning tool will no longer have the new buy lead times calculated form the supplier, but only the shipping times for the centralized warehouse.

If we take the example offered in section 4.8 on a current state decentralized warehouse strategy, we find that the total stock in the system is reduced from $34M to $30M or an 11% decrease. It is observed that $27 Million will be held back at the centralized location. This is based on running the calculation Re Order Point based on the multi-echelon scenario as described in section 3.1.5. Program specific warehouses, will now hold one week of safety stock which is reflective of transit time from the centralized location. The percent savings will vary tremendously based on service level, variance in forecast and lead time, cost of inventory and lead times. This is only a numerical representation.
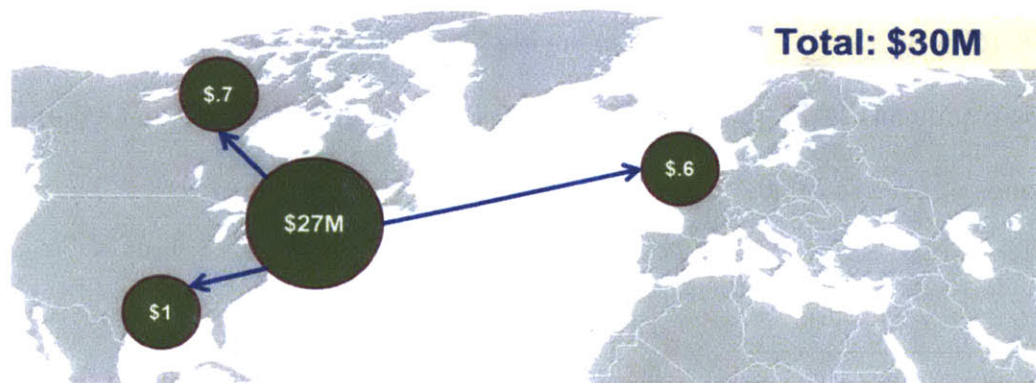

Figure 17: Centralized Warehouse Scenario

5 Conclusion

The +Add model provides a comprehensive and systematic framework for bridging the gap from current state issues to a desired state of agile high performance supply chains that are globally optimized. The key to agility is the ability to see the future clearly (Forecast/new buy accuracy) coupled with the ability to quickly adopted (performance lead times). Aggregation provides significant value, but only after programs level excellence.

No longer can aerospace and defense product support supply chains afford to have elements of the transactional "old way" of doing things. They must add value to the customer by such frameworks as the +Add model, through agile high performance product support chains.
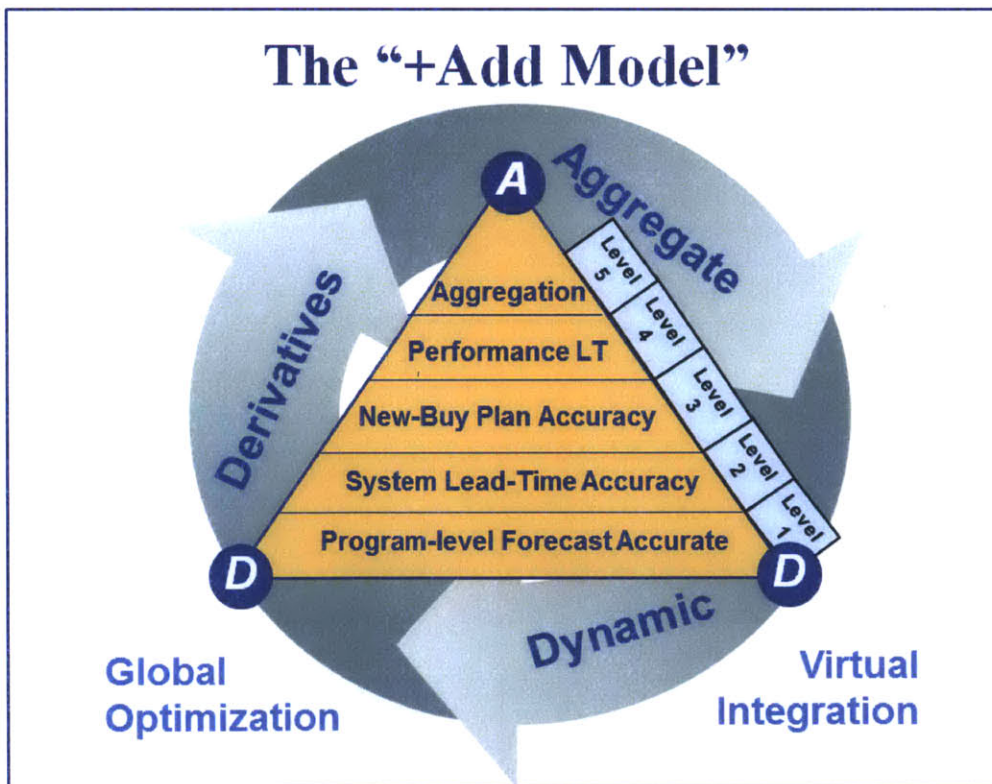

Figure 18: The +Add Model