Process for Evaluating Options for Materials Management Outsourcing

by

Mark Hagan

Bachelor of Science in Engineering Sciences (Chemical), Yale University (1997)

Submitted to the Department of Chemical Engineering and the Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Chemical Engineering and
Master of Business Administration

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Signature of Author ______________________________
Sloan School of Management
Department of Chemical Engineering
May 2004

Certified by ______________________________
Deborah Nightingale, Thesis Supervisor
Professor of the Practice of Aeronautics and Astronautics and Engineering Systems

Certified by ______________________________
Stephen C. Graves, Thesis Supervisor
Professor of Management Science and Engineering Systems

Certified by ______________________________
Gregory J. McRae, Thesis Reader
Professor of Chemical Engineering

Accepted by ______________________________
Margaret Andrews, Executive Director of Masters Program
Sloan School of Management

Accepted by ______________________________
Daniel Blankschtein, Chairman, Graduate Committee
Department of Chemical Engineering

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ABSTRACT

This thesis investigates the issues involved with the outsourcing of the materials management function within aerospace assembly, proposing a process for determining whether all or part of the responsibility should be given to suppliers. A flowchart tailored to the aerospace assembly process has been developed to address strategic as well as cost concerns. This flowchart looks not only at the outsourcing of the entire materials management function, but also at the possibility of outsourcing the management of individual carts of parts to suppliers. In this case, referred to as supplier kitting, existing suppliers package parts in a kit that stops short of a full outsourced assembly, but has many of the same attributes.

At this point, a cost model is proposed for assessing the internal costs of receiving and packaging a single set of parts for use at the assembly line. The cost of receiving, storing, and building up a set of parts is difficult to estimate from the data used within internal accounting systems. The cost estimated by the model can be used as the basis of comparison for outside bids to package parts.

In addition, the broader trend towards outsourcing in the industry is explored, along with the recent implementation of best practices in supply chain management that impact the requirements of the materials management function. Finally, the organizational barriers to making improvements in the organization's supply chain are explored, along with specific examples that are related to materials management.

Thesis Supervisors:
Stephen C. Graves, Professor of Management and Engineering Systems
Deborah Nightingale, Professor of the Practice of Aeronautics and Astronautics and Engineering Systems

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1. Introduction

1.1 Background

Outsourcing has become a dominant topic in the field of aerospace manufacturing. Whereas in the past the major challenge has been the management of a vertically integrated manufacturing enterprise, today's challenges surround the complex management of a large web of suppliers responsible for producing an aircraft. A well managed process that can identify the proper breakdown of work and coordinate activities between suppliers can result in significantly lowered costs for the aircraft.

The motivation to outsource comes from several sources. Boynson et al. list ten prominent reasons for outsourcing as suggested by the Outsourcing Institute[1]. These include both strategic and tactical considerations. On the strategic side, the motivation is to assign tasks to companies with the strongest capabilities. The supplier has the ability to focus on their presumably world-class capabilities in the outsourced task, while the original company can now focus resources and energies on pursuing areas where their own capabilities provide the highest leverage. This model of comparative advantage ideally will yield a long-term economic return on any investment. On the tactical side, cost reduction and capital preservation are the primary concerns.

The major challenge for companies is to determine which of their internal competencies are worth focusing on and which should be outsourced. Fine and Whitney argue that given the importance and frequency of these decisions, this process itself constitutes a core competency of the organization[2]. To help in this process, Quinn and Hilmer[3] outline seven characteristics that indicate the presence of a core competency, asserting that effective core competencies are:

1. Skill or knowledge sets, not products or functions

[1] Boyson, Sandor et al. Logistics and the extended enterprise: benchmarks and best practices for the manufacturing professional, Wiley, 1999. p. 93-101.
[2] Fine, Charles, and Daniel Whitney. "Is the make-buy decision process a core competence?", April 1996.
[3] Quinn, James, and Frederick Hilmer. "Strategic outsourcing", McKinsey Quarterly, 2000, Number 2, p. 52-56

2. Flexible, long-term platforms – capable of adaptation or evolution
3. Limited in number
4. Unique sources of leverage in the value chain
5. Areas where the company can dominate
6. Elements important to customers in the long run
7. Embedded in the organization's systems

Functions that do not fit within the core competency criteria are candidates for outsourcing. Another perspective, presented by Bruck, suggests that vertical integration can be used to reinforce existing competencies in other areas, so long as the company is operationally superior in those areas to competitors in the market[4]. This may be extended to look at third parties that may easily provide service to competitors.

Materials management is one organizational function that could be considered for outsourcing. Ansari and Moderress define the materials management function as comprising the following functions: *purchasing, inventory control, production control, traffic* (arranging and scheduling transportation), *materials handling,* and *receiving and storage*[5]. Within this thesis, these functions are split into direct and indirect functions, where the direct functions of receiving and storage, materials handling, and traffic are along the value stream for the physical part flow, and are sometimes referred to as *logistics*. Purchasing, inventory control, production control, are indirect functions that involve planning and oversight, but not necessarily physical handling of the parts. Within these functions, the same motivations to outsource exist as would be true in any make/buy decision. Lynch suggests nine motives for the outsourcing of logistics[6], paralleling the rationale given by Boynson in the broader outsourcing discussion. For the indirect functions, the decisions become more complex but the reasons equally compelling.

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[4] Bruck, Felix. "Make versus buy: the wrong decisions cost", McKinsey Quarterly, 1995, Number 1.
[5] Ansari, Abdolhossein, and B Modarress. Just-in-time purchasing, Collier McMillan, 1990, p 17.
[6] Lynch, Clifford. Logistics Outsourcing: A Management Guide, Council of Logistics Management, 2000, p 7-16.

The first step in considering the outsourcing of materials management is whether it constitutes a core competency of the firm. When considering logistics, it is hard to argue that any of the criteria listed above apply. While some of the materials handling capabilities required by the aerospace organization are not standard, the rise of successful third-party logistics providers in much higher volume industries with similarly stringent specifications suggests that specialization is possible. It is possible that a company would decide that materials management and logistics is a core competency. In this case, the demonstrated capabilities of the firm would be clearly superior to alternatives, providing a competitive advantage in the marketplace. Another rationale would be that the control of the logistics function is a strategic imperative given unique skills developed for carrying out a specific job. However, in the majority of cases materials management will not be a core competency, but may be a function that is difficult to outsource due to a lack of proper processes, suppliers, or cost advantages. Organizational factors may also play a role in making a decision.

1.2 Thesis Overview

This thesis is concerned with the question of whether to outsource all or part of the materials management function. The focus is on creating a process that ensures that the proper processes are in place for transitioning the function, proper suppliers have been found, and costs have been properly accounted for. It is assumed that in the great majority of cases, logistics will not be a core competency of the manufacturer, and other indirect materials management functions could also be outsourced. A process is proposed to evaluate options once the potential for outsourcing has been established. The outsourcing of the entire function is considered, as well as the possibility of outsourcing responsibility for specific parts of the aircraft. This flowchart, along with an accompanying cost model, provides the basis for evaluating options for outsourcing all or part of the responsibilities of logistics and associated support functions.

1.3 Thesis Outline

The thesis is divided into six sections. Section 1 gives background on the overall drivers pushing the industry to increased outsourcing, and reviews some of the literature on the subject as it applies to materials management. Section 2 examines the aerospace supply chain in general, looking at the supply chain structure, sources of inventory within the system, and business processes being widely adopted to improve performance. Section 3 defines the role of materials management system within the aerospace industry, and looks at how the adoption of new business processes for reducing inventory is creating pressure to adopt new systems for warehousing. The critical role of kitting and carts is explained. Section 4 proposes a decision making process for evaluating the outsourcing of materials management activities. Outsourcing of individual carts is considered as well as outsourcing of the entire materials management system. A flowchart is proposed for guiding the process along three key steps – *examination of internal processes, evaluation of supplier capability,* and *cost analysis*. Questions are posed at each step, depending on the type of outsourcing being evaluated. Section 5 introduces and explains a cost model that is required to make rational decisions in the case where less than the entire process is outsourced to suppliers. An example is used to illustrate the mechanics of the cost model in evaluating a typical outsourcing decision. Section 6 draws some conclusions about materials management outsourcing, and touches on some of the organizational barriers that constrain the implementation of change in this area.

2. Project Context

2.1 Motivation for Supply Chain Improvement

The improvement of supply chain management practices has become an area of focus in the aerospace industry. Global competition, along with the advent of performance based defense contracts[7], has increased the pressure to reduce the cost of aircraft builds. At the same time, aerospace integrators are increasingly choosing to focus on a limited set of core functions, partnering with suppliers who are responsible for delivering a large fraction of the aircraft value. Finally, the cyclical nature of the industry has put a premium on ensuring that inventories are kept low to reduce exposure to risk, while at the same time avoiding part shortages that will prevent the fulfillment of customer orders. The efficient and careful management of the supply chain can lead to a significant competitive advantage across a variety of programs. When managed poorly, as when a parts shortage shut down the assembly lines at Boeing during peak operation in 1997, the results can be disastrous[8].

In response to this pressure to improve performance, most of the largest US aerospace companies are now members of the Lean Aerospace Initiative, a consortium based at MIT focusing on promoting lean practices within the aerospace industry. While the subject matter of this initiative ranges from product development to manufacturing, a large segment is devoted to the study of supplier networks within aerospace. This workgroup has developed a tool to assess the maturity of supplier networks within the industry, and has helped to bring an alignment of best practices within the industry[9]. This section will look at an example of one representative aerospace supply network, and then discuss the major factors involved with managing parts inventory in such a program. Finally, it will outline a set of best practices which are being applied throughout the industry to improve the overall supply chain performance. All of this is done to give the

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[7] Gansler JS, "Incentive strategies for defense acquisitions", Department of Defense Memorandum, Jan 2001.

[8] "Boeing's Secret: Did the aircraft giant exploit accounting rules to conceal a huge factory snafu?" Business Week, May 20, 2002.

[9] Bozdogan, Kirk. "Lean Aerospace Initiative supplier management assessment tool: version 1.0", March 2004.

reader an understanding of the overall supply chain problem so that the materials management problem can be understood in the proper context.

2.2 One example: RAH-66 Comanche helicopter

The supply chain for an aircraft build is a complex problem to manage. One example of such a supplier network was present in the RAH-66 Comanche helicopter. Although the project was recently terminated, this reconnaissance helicopter, a product of a joint venture between Sikorsky Aircraft and Boeing Rotorcraft, was entering the initial production of nine test units during the second half of 2003. In this case, final assembly took place at a Sikorsky facility in Bridgeport, Connecticut. While a number of parts were manufactured at Sikorsky and Boeing facilities, most of the dollar value of the aircraft was to be produced by suppliers located throughout the US. At full production, approximately ten thousand distinct parts were to be integrated into the aircraft every three and a half days using a pulsed moving line. These parts, ranging from simple screws to the world's most advanced radar and control systems, were all to be subjected to intense quality and cost controls. Once they arrived in Bridgeport, all but a few parts were to be integrated into packages for mechanics to install onto the aircraft. The supplier network and associated business processes needed to be constructed to avoid parts shortages while holding minimal inventory, ensuring rapid responses to program changes, and achieving the lowest possible overhead costs. This performance was critical to meeting the cost and schedule targets for the overall program. In the case of Comanche, suppliers played a major role in delivering major subsystems for the aircraft, making coordination with suppliers the key challenge in meeting program goals.

In managing this complex system, the Comanche program also set out ambitious goals for reducing parts inventory within the final assembly area. Almost all parts storage areas were eliminated in the floor plan. Space was only allocated for one set of parts that would sit next to the line in small supermarkets, putting pressure on the system to deliver parts to the line just in time, a task that would require better performance as production ramped up from less than one aircraft per month to as many as eight aircraft per month. The goal of the plan was to reduce not only incremental inventory holding costs, but to eliminate the fixed costs of maintaining a parts warehouse. Together with the complexity of the supplier network, this challenging goal put pressure on improving the supply chain performance. To better understand the challenge of eliminating inventory, the following section will look at the sources of inventory in the system, with an emphasis on US defense aircraft programs like Comanche.

2.3 Inventory Management

2.3.1 Sources of Inventory

Nahmias describes seven reasons for holding inventory in the production process[10]. Most of these can be lumped into two categories: inventory resulting from lot sizing and inventory resulting from uncertainties. Lot sizing criteria can come from economies of scale, control costs, or ordering rules. This creates cycle stock. In many cases, the most economic order size for a part is higher than the amount needed to build one aircraft. Many aircraft parts are of very high value. Also, volumes are typically low, making the timing of shipping a small consideration in setting order size. These parts are then good candidates for single piece delivery from the supplier to the line. Still, a large fraction of parts will be delivered in higher quantities due to the costs of transactions relative to part values. This requires that more than one part be held in inventory at one time.

Uncertainties drive the rest of the inventory in the system. One such example is obsolete inventory. This is the result of changes in design that cause some parts currently in inventory to become unusable in future builds. This inventory could not exist without the initial presence of other inventory, leading to the possibility of obsolescence in the first place.

The rest of the inventory is safety stock, and it comes from two major sources. One is uncertainty in customer demand. The other is unpredictable variation in supplier or internal processes. Inventory resulting from variation in customer demand can be reduced through better forecasting, the shortening of replenishment times, or the active management of customer orders to smooth natural variation in demand. More

[10] Nahmias, Steven. Production and Operations Analysis, McGraw-Hill, 2001.

troublesome is safety stock required due to variation on the process side. This results from variations in processes that should be controllable. These two sources of safety stock are broken down in more detail below.

2.3.1.1 Demand Uncertainty

Production Parts

In new defense programs, customer demand is known well in advance. While changes to customer requirements do occur, the delivery schedule is set well in advance. In the case of commercial aircraft, or of foreign sales of defense aircraft, modifications to customer orders may occur late in the build process, requiring that inventory of different types of parts be kept to meet demand for different variations of products. Still, nearly all large aircraft are built to order, and demand uncertainty does not play a major role in inventory levels.

Spare Parts

Unlike production parts, spare parts are subject to large variations in customer demand. Spare parts make up a large fraction of the value of a defense contract, often taking up more than half of the total program value by the end of an aircraft's lifetime. Forecasting of spare parts demand is notoriously difficult, but advances in "intelligent" aircraft systems offer the promise of being able to detect part maintenance requirements in advance of the customer need. For spare parts, demand uncertainty plays the largest role in determining inventory levels.

2.3.1.2 Process Uncertainty

Supplier On-Time Delivery

Late part deliveries can come from many sources. Often, they result from engineering or schedule changes introduced by the aircraft integrator. In other cases, they are the result of poor planning or processes at the supplier. The predictable, on-time delivery of parts is an important factor in limiting the buffer of inventory needed to keep the line running smoothly. For this reason, suppliers are continuously evaluated on the basis of their on-time delivery, with the potential of penalties if performance does not meet standards.. In one mature program, supplier on-time delivery metrics of over 99% were used to evaluate suppliers.

In cases where supplier on-time delivery is the key uncertainty in process planning, it is possible to implement a model utilizing lead-time variation as the key input for sizing inventory buffers. In the simplest version of this model, a known customer demand is assumed, and the required inventory buffers can be calculated to meet a specified probability of receiving the part when needed. An extension of this model, described by Ronen and Trietsch[11], shows how the assembly process can be modeled to set inventory levels to complete a build at the minimum cost while ensuring a given overall fill rate. While such a model is possible to build, it does not attack the sources of variation that lead to the safety stock levels to begin with. In the case of supplier performance, variation in lead time or quality is not unavoidable. While a model can be used to set initial levels of inventory, the focus should be on reducing variation and lead times to reduce inventory levels. If process variation is taken as a given, high levels of inventory may be built into the system without any mechanism for future reduction.

Part Quality

Additional inventory is often built into the system to deal with the possibility of having a part of poor quality. This is especially important when inventory levels drop to levels of one or zero. If a just in time system is used, a single quality problem on a critical part can cause an expensive workaround on the shop floor or even a line stoppage. For this reason, it is rare to have a part in aerospace delivered just in time. Even if supplier quality levels approach 100%, there is still the possibility of the part being damaged within the warehouse or assembly areas. When inventory levels higher than one are considered, part quality does not play a major role in setting inventory levels, although it is tracked carefully to evaluate supplier performance.

[11] Ronen, Boaz, and Dan Trietsch. "A decision support system for purchasing management of large projects", *Operations Research,* 36(6), Nov-Dec 1988.

Adherence to Work Schedule

The final process variation that is important in determining inventory levels is the uncertainty of when a part will be needed at the assembly line. While final customer demand may be well known, the aircraft assembly process can stretch for weeks or even months. When the actual build of the aircraft does not match the assembly schedule used to order the parts, inventory builds up. This can result from unpredictability within the actual assembly process, but also results from the variation in the delivery of other parts to the line. In this way, poor performance from one supplier can cause a ripple effect whereby work is rescheduled, leading to excess inventory or shortages of other parts.

2.3.2 Setting Inventory Levels with Min/Max Systems

In a min/max system, inventory levels are kept within upper and lower bounds at all times. There is flexibility on what reorder point is used for material, so long as the level of inventory never drops below the minimum. It is possible for the integrator to manage this through traditional planning and ordering processes, setting an automatic reorder point that takes into account both the minimum and the lead time, but ideally, the supplier has visibility into the system and can manage shipments directly. This flexibility allows the supplier to plan around their own production constraints to satisfy the customer in the most cost-effective manner. This can also be viewed as a simple version of vendor-managed inventory.

2.3.2.1 Using A/B/C Classifications

Setting the appropriate min/max level is critical, as it will determine the inventory costs for the program. For parts where scrap on the production floor is an issue (whether due to frequency or severity of the consequence), a minimum of at least two should be set so that there is an extra part available. Otherwise, minimum levels should be set based on the capabilities of the supplier, the regularity of part consumption, the cost of holding inventory, and the severity of the consequence of a shortage. As a first cut, parts may be assigned minimum levels based on A, B, or C inventory classification, where A parts represent the highest and C parts the lowest value parts. Minimum levels would then be assigned on a "weeks of inventory" basis, where less "A" inventory is kept than "C" inventory. If more detailed information is available on a part, these levels can be tweaked up or down. For example, if a part is on the critical path, it may be advisable to keep an extra part in storage. On the other hand, if a part can be easily worked around and supplier performance is excellent, it may be possible to reduce the minimum kept in storage.

2.3.2.2 Using data-driven models

One way of determining the proper min/max levels to set is to use historical data to determine the optimal levels. Supplier on-time delivery, variability in part consumption, and part quality data would be used to predict variability in part arrival, and the inventory holding cost for the part and the cost of a part shortage would be used to help determine the optimal service level and amount of buffer stock to be kept.

In practice, the cost of a part shortage is very difficult to estimate or model. Also, the use of a min/max system makes variances in supplier lead time difficult to estimate, as suppliers are no longer held against a delivery date and have significant planning flexibility. This makes it impossible to directly measure lead time or even variation around a promised delivery date. In a min/max system, there are no promised delivery dates. Instead, supplier performance is measured by looking at how frequently inventory levels go outside of the min/max bounds. Together, the difficulty in measuring the cost of a parts shortage and the lead time of a supplier makes it difficult to construct a useful inventory model that can be used to consistently revise levels.

However, a simple model could still be used to guide initial min/max levels. This would look simply at the variation in the timing of part consumption while using a standard lead time. This model assumes that the majority of process variation caused by suppliers will be reflected in variation in part demand on the factory floor, and that individual supplier performance can be attacked directly when setting initial min/max levels for broad ranges of parts. A specified service level would be used to determine inventory requirements, using an A/B/C classification to account for the significant variation in inventory costs between different parts. For example, a C part, where the cost of holding inventory is relatively small, may require a 99% service level, whereas an A part may require only a

95% service level (assuming the cost of a shortage is similar between parts). While such a model does not address the detailed performance of suppliers delivering individual parts, this simple system can guide broad inventory policy for a program to levels appropriate for the program's level of supply chain and operations performance.

This is meant to serve only as an initial guide for setting levels. One of the attractions of a min/max system is that it lends itself well to a trial and error system for reducing inventory. The minimum can be lowered slowly over time, with each drop in the level producing a corresponding drop in inventory holding costs. This reduces the risk of starving production when minimum levels drop far below the levels required to cope with process uncertainty.

The maximum level can be set by looking at the ideal lot size for a part and adding that to the minimum level. That ideal lot size should be set in accordance with existing policies, taking into account inventory and ordering costs. In many cases, lot sizes of more than one will still be necessary due to the substantial "setup costs" involved with ordering, producing, receiving, and stocking parts. Also, many part numbers may have more than one unit per ship set. This should be taken into account in setting the maximum level.

2.4 Key Business Processes

The RAH-66 Comanche is just one example of many programs with supply chain challenges. Some new programs are outsourcing more assembly responsibility to suppliers, pushing some of the integration activity away from final assembly but not eliminating any of the overall supply chain complexity. From new commercial aircraft like the Airbus 380 and the Boeing 7E7[12], to new defense aircraft like the international Joint Strike Fighter[13], an increasing amount of assembly and design work is being done by suppliers outside of the final assembly hangar.

[12] "Boeing goes abroad for 7E7 work", Flight International, November 2003.
[13] "Delivering the promise - Joint Strike Fighter", Flight International, November 2003.

To help streamline this process, a number of best practices have emerged, all aiming at reducing the complexity and variation of the process. This has been manifested in a set of specific practices all aimed at making sure that high quality parts are delivered at the right time, to the right place, at the lowest possible cost. Many of these practices are aimed directly or indirectly at reducing or mitigating the effects of process uncertainty, the major cause of high production inventory in defense aerospace programs. The ability to successfully implement these practices should lead to greatly reduced inventory levels, affecting the way that materials are handled within the factory. These processes are described below, along with a description of their advantages and the challenges of implementation.

2.4.1 Consolidated Supplier Base

Traditionally, the desire to have competitive sourcing has led to a large supply base. In many cases, suppliers are not actively supplying product, but they are still available to buyers for new purchases. While competitive sourcing is still an important part of the procurement process, there are several good reasons to limit the number of suppliers used by the organization. All of these lead to reduced costs that should offset the possibility of higher price due to less intense competition in the bidding process. The primary advantages are:

1) Focusing on the highest performing suppliers – those that not only delivery parts at low cost, but also work well with the organization to meet quality, on-time delivery, and other supply chain improvement goals - and removing low performing suppliers from the supply base can reduce the cost of quality and supplier oversight. Low performing suppliers cause more disruption to the production process and require more oversight than high performing suppliers. Placing more business with high performing suppliers provides an incentive for existing suppliers to maintain or improve performance to avoid being excluded from future business.

2) A reduced supplier base makes it possible to provide the oversight necessary to certify suppliers and perform the process surveillance necessary to ensure product

quality without inspection. Regardless of whether or not a supplier is supplying much or any product, any supplier in the supply base will have to meet certain criteria to provide product, taking up the time of staff required to maintain that certification. By simply having fewer suppliers, the cost of managing the supply base will be reduced. Using fewer suppliers also eases the transition to using pull systems, as fewer suppliers need to be transferred to a new system to start using pull for a large percentage of parts.

3) The use of a smaller number of suppliers, each of which now provides more parts to the aircraft, allows for greater purchasing power with each supplier through higher volume purchases.

As a counter-argument to this, Dyer et al. suggest that suppliers be segmented into two models, an "arm's length" model and a "partner" model, arguing that the partner model is not appropriate for all suppliers[14]. Even with the qualification of using competitive, arm's length bidding for some transactions, particularly those that require little unique technical ability or development, the trend in the industry is clearly towards reducing the supply base.

With this smaller supply base comes an increased focus on choosing the right suppliers to keep in the supply base. In his paper on supplier management in the defense aircraft industry, Shapiro discusses many of the systems developed recently to assess and select suppliers. As a first step, companies use a supplier certification system to ensure that high quality suppliers are being used for contracts. These suppliers may be further tiered to separate high performing suppliers. Metrics such as on-time delivery, quality, and cost reduction are used to monitor ongoing performance. The goal is to create a manageable portfolio of suppliers capable of meeting the contractor's needs over a range of programs and uncertainties[15].

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[14] Dyer JH, Cho DS, Chu Wujin. "Strategic supplier segmentation: the next best practice in supply chain management", California Management Review, 40 (2), Winter 1998.
[15] Shapiro, Jeremy. "An overview of supplier rating, certification, and selection systems in the defense aircraft industry", MIT Paper, March 1995.

With reference to the Comanche program, both Boeing and Sikorsky are working to consolidate their supply bases. Both in and beyond the aerospace industries, other large integrators are moving towards improved supplier relations with a smaller number of suppliers. This trend is pushing suppliers to be more responsive to measures other than cost when making bids, as it is recognized that the supplier may be excluded from future contracts if they do not participate in programs such as pull, data integration, and concurrent design.

2.4.2 Use of Long-Term Agreements with Flexible Delivery Dates

There are two main reasons for pursuing this. The first has to do with the length of the agreement. By using long-term agreements, lower prices can be negotiated with suppliers. Higher volumes attained over longer time horizons result in lower prices. Also, suppliers have a greater incentive to invest in cost saving capital investments if they are more confident in having ongoing orders over which to spread the costs.

The second advantage comes from the flexible delivery dates. This is a prerequisite for pull systems, allowing the actual date of delivery to be triggered by some mechanism other than a purchase order as long as overall production targets remain within specified bounds. In the past, this would either result in the transaction cost of a buyer changing a PO, or the inventory cost of receiving the part early as the item was shipped to the original schedule. Either way, some cost was involved that is eliminated by using flexible delivery dates, where the date can be changed through an automated process without incurring any penalties.

2.4.3 Quality System Promoting Supplier-Certified Parts

Three general types of quality control are used in the aerospace industry for incoming purchased parts. The first is receiving inspection, where parts are inspected as they are received at the assembly facility. The second is source inspection, where a representative of the integrator will inspect the part at the supplier before it is shipped. The third method puts the burden on the supplier to promise the part is of acceptable quality, removing the need for either source or receiving inspection. These parts are then delivered to the facility with a certificate promising high quality. A system that emphasizes the use of supplier certified parts has several advantages over parts requiring inspection.

1) The use of source and receiving inspection creates uncertainty in the lead times between the supplier's dock and the assembly line. When many parts need to be inspected, the delay of parts getting to the line can stretch for several weeks as inspectors are stretched thin and queue lengths build. This requires that appropriate buffer stocks are planned into the system to allow for the possibility of additional flow time.

2) The need for receiving inspection limits flexibility in delivering parts to different locations. Parts requiring receiving inspection need to be shipped into one location. In many cases, it is more desirable to ship the parts directly to the line or to different warehouses. This impacts spare parts as well as production parts, limiting the ability to ship directly to a spares warehouse or to the customer. Parts that don't require receiving inspection can be shipped directly to where they are needed, eliminating parts handling and flow time.

3) There are cost advantages to using a supplier inspection process. Fewer inspectors are typically required, and those who remain can now be used to work with suppliers to improve their processes to provide higher quality, rather than acting simply as gatekeepers. Additionally, the intangible advantage of giving suppliers ownership over the process has been credited with improving performance.

During the course of this internship, one major defense aerospace program was observed that currently has 96% of parts on a system where the supplier certifies the quality of the part without either source or receiving inspection. The quality team at this facility credits the system with reducing receiving inspectors from 45 to 3, reducing the field quality force by two-thirds, and improving all recorded quality metrics. At the same time, this has made flow times shorter and more predictable, facilitating the use of pull systems with suppliers without buffer stock. Due to the low volume of parts going through receiving inspection, queue times for the 4% of parts remaining are under one hour.

2.4.4 Electronic Data Integration

The use of electronic systems to communicate data to and from suppliers is becoming critical to managing projects cost effectively. These systems have four key advantages:

1) Speed – by making data available electronically, it allows the latest information to be made available to everyone within the enterprise instantly. This shortens cycle times on design changes, schedule changes, and other communication.

2) Reduction of transaction costs – paperless electronic databases make it possible for many transactions to occur automatically, without human interaction, allowing the buyer to focus more on management than repetitive tasks better done by the computer. Remaining transactions can be carried out more efficiently

3) Quality – the use of electronic systems makes it less likely that errors will occur in the process of communicating information to or from the supplier. The systems also make it easier to track tasks, avoiding the possibility that important tasks will fall through the cracks and making it easy to track metrics.

4) Visibility and communication – through web-based systems, suppliers can easily gain visibility into production schedules and other information that allows them to fulfill their commitments in the most cost effective manner possible.

The development of web-based systems for sharing and communicating key data with suppliers is an expensive task. This requires that both integrators and suppliers improve their own capabilities considerably. In many cases, smaller suppliers will be slow to adapt the new systems. Despite the high hurdles to developing such systems, many integrators have already come a long way towards integrating suppliers with their systems. For example, Exostar is an online marketplace founded by Boeing, Lockheed Martin, Raytheon, and BAE systems to manage supplier bids, contracts, and purchases, leading to lower transaction costs and cycle time reduction[16]. In the case of the RAH-66 Comanche program, both lead contractors had developed web portals for communicating part delivery schedules with suppliers, sharing part data, and tracking supplier performance.

2.4.5 Adoption of Pull Systems

In a perfect assembly operation with a known delivery schedule, it should be possible to use an MRP or other push-based system to delivery parts just as needed to the line. In reality, parts shortages, spare parts demand, unplanned machine downtime, legitimate schedule changes, or other factors lead to unpredictable changes to production schedules. By bringing parts into the factory on a pull system, it is possible to allow the system to adjust automatically to these deviations from plans, avoiding the need to carry extra inventory. The ability to implement pull systems is the payoff of the work required to implement the other initiatives mentioned above, as it embodies the low inventory, low transaction cost system desired in a smoothly operating supply chain.

2.4.5.1 Requirements for Pull

Each of the enabling initiatives described above is necessary for effectively implementing pull systems. However, there are other elements required to make pull systems work properly, as described below.

First, pull systems will only provide their maximum benefit if work stays close to schedule. If work was always perfectly on schedule there would be no need for pull, and parts could be scheduled deterministically. However, if work is radically off schedule, and there are frequent, unpredictable bursts in an effort to catch up, it is impossible to run a pull system without having the supplier carry excessive inventory. Sticking to schedule

[16] Juergens, Bob. "Exostar: e-procurement and supply chain integration", Presentation to Lean Aerospace Initiative workshop: Building Internet-Enabled Integrated Value Networks, January 30, 2001.

has direct cost benefits in the assembly process, but it is also critical in reducing process uncertainty and inventory.

Second, going to a pull system puts pressure on the supplier to have a lean operation that can cope with the variation in demand without carrying excessive amounts of inventory. A supplier would prefer to have clear ship dates for parts, as it makes it easier to plan their own production requirements. By going to a pull system, the enterprise is effectively going to a system with ship dates that can change constantly. For this reason, it is important to assess the capability of the suppliers before putting them onto a pull system. Otherwise, smaller suppliers may be effectively set up for failure, as they are forced to carry high amounts of inventory or watch their supplier ratings drop.

A third requirement for pull is that suppliers have some visibility into future requirements so they can plan their overall production rates. This is necessary for suppliers to make sure they have the resources available to meet target ship dates and inventory levels. For example, if a supplier expects to deliver 52 parts per year, one each week, and five parts are unexpectedly consumed at once, it is unlikely that the supplier will be able to meet that demand within the usual lead time. If parts consumption is highly unpredictable and suppliers are still expected to deliver on time, all that is being accomplished is that buffer inventory is pushed back onto the supplier. This is advantageous in the short run as inventory costs go down, but the added cost for the supplier will eventually be reflected in higher prices. By giving the supplier some visibility into the production requirements, they can plan for these spikes in consumption in the most cost-effective way. Also, for this reason it is important to stay on schedule.

2.4.5.2 Different varieties of Pull Systems

A pull system does not necessarily need to follow the *kanban* style approach of the Toyota Production System. Three different approaches to pull are described below, along with the pros and cons of using them in different scenarios.

Ship to MRP schedule rather than a purchase order

This requires supplier visibility into the production schedule, but allows them to change shipping dates as the MRP date changes. In many ways this is still a push system, but it is similar to more conventional pull systems in that it allows shipment dates to automatically vary as the MRP system is updated. This method does not work well when actual production usage is not in line with MRP, but even in this case it is better than relying on formal change orders to alter shipping dates due to the transaction costs involved in that process

This system is most effective for parts with occasional or irregular requirements that can be forecasted through the MRP system. While the MRP system does not exactly match consumption on the floor, there is no other trigger that can better convey the desired delivery time for the part. For pieces in regular production, it should not be necessary to use this type of system.

Ship to a min/max level

In this system, the supplier still maintains visibility into the production schedule, but is required to maintain inventory levels at the factory within a minimum and maximum level. Therefore, they are also given visibility into the inventory level at the factory. Another version of this is supplier-managed inventory, where the supplier actively manages inventory levels inside of the factory. This version can be viewed as a min-max system with outsourced oversight and ordering functions.

This system works well for parts in flow with regular consumption, except for parts that require a minimum of zero parts in storage. In those cases, it is difficult to schedule the date of the delivery of a part within a takt time, or part consumption cycle. For example, if a part is consumed once every five days, and it is best to deliver the part on day four of the cycle, one day before it is due to be consumed, a min/max system can not distinguish between delivery on day one or day four. Both result in either having zero or one piece in inventory. However, the majority of parts can be put on a min/max system, as minimum levels often need to be set higher than zero and delivery within the takt time is often not critical for meeting performance targets.

Discrete pull

In this system, a new shipment is triggered by an event on the production floor, such as consumption of a previous shipment. This keeps a continuous pipeline of parts en route to the line. This system works best when the specific timing of a part delivery within one takt time (or parts consumption cycle) is important. This typically applies to very high dollar-value parts, but can be extended to other parts as performance improves.

This system operates on the typical kanban principle. As a part is consumed, a kanban card is sent to an upstream operation, requesting replacement of that part within a given timeframe. The number of kanban cards in the system is regulated to maintain the total inventory in the system at a constant level. It should be noted that any of the parts that can be put under min/max can also be put on a kanban system. The min/max system typically provides more flexibility for the supplier, whereas a kanban system more effectively relays the production pulse throughout the supply chain with less flexibility.

Discrete pull is best implemented in systems with regular consumption and very good communication between the supplier and lead contractor. For this reason, it makes sense to use discrete pull for internal processes at first, and then transition to using it for external suppliers. If it will not work within the walls of the factory, discrete pull is unlikely to be successful with external suppliers where communication barriers are higher.

2.4.6 Implications for Materials Management

The implementation of these new processes is putting new pressure on the materials management system to be efficient and reliable. When inventory levels were high, flow times of several days may have been acceptable to bring a part from the receiving dock to the warehouse, then on to the assembly floor. With very low inventory levels, materials management functions can become a substantial factor in preventing a company from achieving a just in time system. Similarly, the direct costs of the materials management system are becoming a larger fraction of overall costs as processes for purchasing improve and inventory drops. This makes materials management a candidate for cost reduction initiatives, including the possibility of outsourcing.

Additionally, lower inventory levels mean that materials management systems may be forced to abandon the traditional approach of storing parts in a warehouse between the supplier and the line. A pull system can be "disconnected" at any point along the supply chain. Material can be pushed into a warehouse, and then pulled as needed from the warehouse, with inventory in the warehouse fluctuating as the push and pull rates go up and down. With the introduction of new practices that allow pull signals of various forms to be sent from the line all the way back to the supplier, such a decoupled system is not necessary. This means that the warehouses themselves may be replaced by systems where parts are managed on the shop floor in much smaller spaces, with tight control over the levels of inventory used for each part. This changes the systems required for controlling parts, and opens up the opportunity for major cost reductions.

3. Materials Management Systems

3.1 Main Functions

The materials management system receives parts from suppliers and puts them where they are supposed to be. Receiving, storage, transportation, and delivery to the line are all part of materials management. From a broader perspective, functions such as production control, delivery scheduling, and shipping are also part of the materials management system. Another responsibility that has evolved in recent years is the need to package parts into kits that are suitable for presentation to the mechanic. This is described below.

3.2 Kitting Requirements

In the past, mechanics working on the assembly line gathered for themselves the parts necessary to perform their jobs. Recently, many assembly operations have moved to kitting, where packages of parts are prepared by specialized personnel and presented to the mechanic as needed. This frees mechanics from having to locate parts, allowing them to focus on assembling the aircraft. Unless a supplier ships an integrated kit, this operation is performed at a warehouse or kit consolidation area, where all the parts are gathered and inserted into kits. These are then taken out to the line as needed.

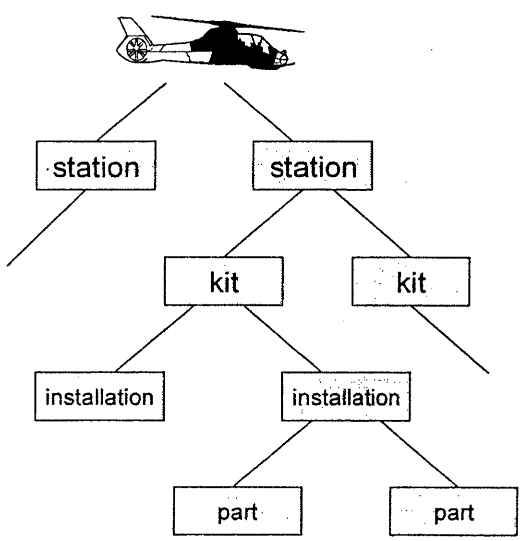
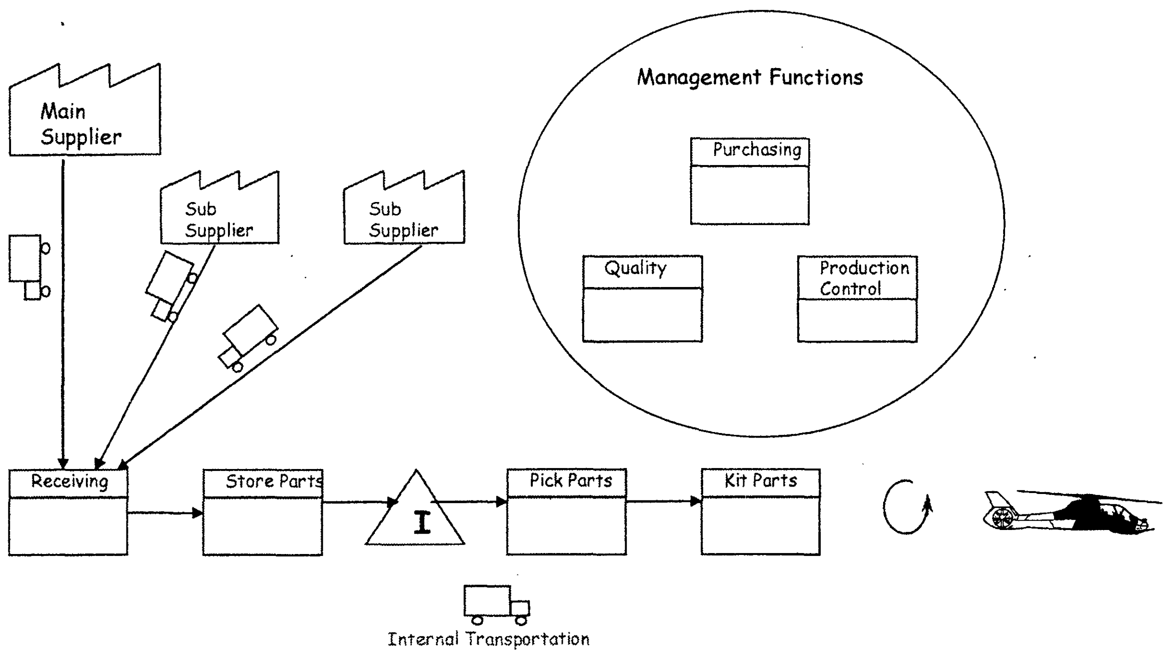


Figure 1: Parts tree showing role of kits in assembly process

Kits are made up of installations, which are the building blocks of the assembly process. Each installation represents one set of standard work, normally a 4 to 8 hour job for one or two mechanics. These installations may contain any number of parts, depending on the complexity and size of the task. Kits may contain only a few parts from one supplier, or hundreds of parts from dozens of suppliers. The composition and order of these installations is determined through detailed analysis of the assembly process. In an effort to properly balance the line and improve the assembly process, the details of these installations may shift frequently, especially early in a program when experience with the process is low.

3.3 Traditional Process

The process used during the Engineering and Manufacturing Development phase of the RAH-66 Comanche helicopter program is typical of the aircraft assembly receiving and kitting process in general.



For any given section or assembly of the aircraft, parts will arrive from a number of internal and/or external suppliers. At the receiving dock, parts are logged into the main MRP system to register receipt. From there, parts that require inspection are set aside for receiving inspection. Unless they are flagged for expediting in the system, the rest of the parts are put into storage in a warehouse area. Several days before a part is needed at the assembly line, a request for a full kit of parts is made to the warehouse. The required parts are picked from storage, put into kits, and sent out to the assembly line.

Parts are delivered by materials management personnel to the given assembly line position in which they are needed. In the case of the RAH-66 Comanche assembly line, over 100 kits were required to provide parts to 12 assembly positions. At a full production rate, these carts would be refilled or cycled once every three and a half days over two different shifts. Pressure would be put on the materials management organization to respond as quickly as possible to a request for a new set of parts. Maintaining high service to the assembly line requires a substantial organization to support these processes.

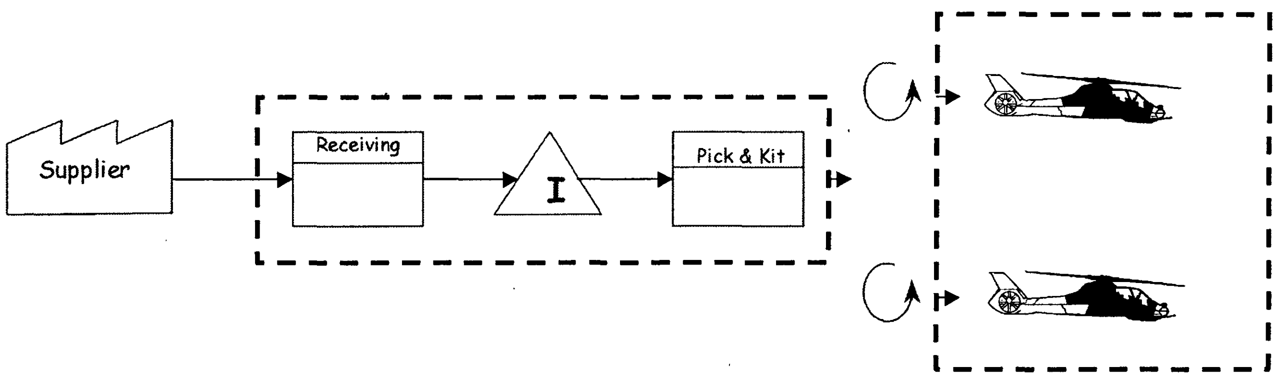
Beyond these core functions, several indirect costs of materials management are also associated with this process. The parts must be ordered and scheduled for delivery to the warehouse at a specified time. This is a job handled jointly by the Purchasing and Production Control groups. Historically, Production Control would set a master production schedule showing the actual needs of the shop floor, and Purchasing would create the necessary contracts with suppliers and schedule the part deliveries according to existing inventory policies. Recently, these job functions have been merging, with closer coordination between Purchasing and Production Control leading to inventory reduction opportunities and reduced staffing needs. Finally, Supplier Quality can also be considered a major support function of the part delivery process. This function is responsible for monitoring the quality of the parts delivered by suppliers to the factory.

3.4 Warehousing Strategy

There is no one perfect approach to receiving, storing, and kitting parts. During this student's internship, several facilities were visited and surveyed. All were found to be implementing some or all of the best practices described in the previous section, and all had the same basic requirements outlined in the flowchart above. However, each had a different approach to the physical handling of the parts value stream. Often, the approach has been dictated by legacy processes, and organizational barriers or capital investment hurdles make it difficult to change. However, in the case of a greenfield plant, these constraints do not exist. This makes it important to understand the various options available for materials handling up-front, as once a system is put in place it will be increasingly difficult to change. This section outlines the basic options available, and presents an approach to make a decision about which warehousing strategy is best for a new program.

3.4.1 Observed approaches

3.4.1.1 Central Storage Approach (Most Common)

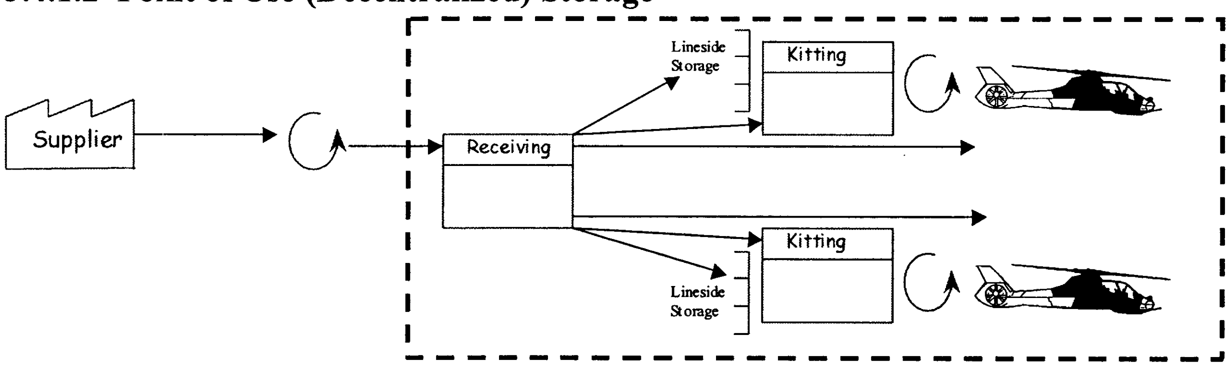


In this approach, parts are received into the facility and placed into storage. Parts are picked from storage when a signal is received from the line. The two processes are decoupled by an inventory buffer, or warehouse, that can hold any number of parts.

This approach provides several advantages. First, it provides some scale to the operation, allowing one materials handling facility to serve multiple locations. Second, it makes it easier to keep track of inventory, as it is all kept in one location. Third, it isolates the materials handling process from the assembly process, allowing each area to focus on their own responsibilities. Finally, it is a very flexible arrangement, allowing for frequent changes in kitting requirements and inventory levels.

With these advantages come several disadvantages. This setup effectively decouples the procurement process from the assembly line. This makes it easy for inventory to build up between the two processes. Similarly, the great flexibility the process provides removes some of the incentive to improve processes that might otherwise exist. In addition to this tendency to build inventory, the process itself involves more touches and transportation than are absolutely necessary to get the parts to the line. Ideally, parts could flow directly to the line without having to pass through an intermediate facility, be put into a warehouse, and be retrieved from a warehouse. This adds cost to the process of getting parts to the line.

3.4.1.2 Point of Use (Decentralized) Storage



In the point of use approach, any parts that need to be stored are kept in supermarkets right at the line. Inventory levels are planned by the size of these supermarkets, with the idea that levels will be minimized to as low a level as is practical. When possible, parts are placed directly into kits for the mechanics, minimizing the number of touches necessary to prepare parts for presentation. This approach also eliminates the need for a separate warehouse.

The main advantage of this approach is that it eliminates the high overhead costs of maintaining and staffing a warehouse, while reducing labor costs by minimizing the number of touches required to get a part to the line. It also forces discipline onto the process, running the entire process on a pull system back to the supplier and minimizing the possibility of building up inventory.

The disadvantages of this approach include the difficulty in maintaining accurate inventory across many decentralized locations, the amount of floor space required for the parts at the line, and the lack of flexibility the process gives for accommodating process errors.

These disadvantages will be less important as process quality and discipline improves. The feasibility of using this approach depends on the ability to run with little or no inventory and the space available. Also, this in essence turns the shop floor into an uncontrolled warehouse, making discipline by the local teams a critical requirement for implementation. Finally, since by definition these areas are located inside the factory, the opportunity for outsourcing some or all of the materials handling work will likely be limited by any existing labor agreements.

3.4.1.3 Other Approaches

Many hybrid or similar approaches to these can also be used. For example, parts may utilize the supermarket approach of the point-of-use storage system while keeping the parts in one central location. In a different factory observed as part of this student's internship, parts were kept at a variety of warehouses. From there they were shipped to the assembly facility, where single ship-sets of parts were built up in a kit building area. In another area, the entire operation was being handled by an external contractor that served as an outsourced central storage and kitting facility. For the basis of this discussion, only the central storage and point of use systems are considered.

3.4.2 Pros and Cons of Approaches

The following table summarizes the pros and cons of the central and point-of-use storage approaches for production parts.

Point of Use Storage	***Central Storage***
• No need for warehouses • Minimum number of touches • Forces discipline in process • Harder to control inventory • Risk of shortage if processes don't perform • Outsourced labor less practical • Space may be an issue in many environments	• Highly flexible • Isolates materials handling from assembly line, allowing specialization • Possible to outsource operations to third party • Requires warehouse • Multiple touches required • Little visibility of inventory

In addition to these concerns, two other issues are important. With respect to outsourcing, it is more difficult to outsource the entire materials management process when implementing a point-of-use storage strategy. Given the complexity of integrating external labor with processes within the factory, it is easier to keep the entire process outside of the factory walls, with internal labor handling the delivery of full carts from a truck to the line. This is especially true in a union environment, where it would be especially difficult to have external employees working side by side with union employees.

Another important concern is how spare parts will be handled. So far, we have only been concerned with production parts. However, over the lifetime of a program, spare parts requirements will likely be on the same order of magnitude as production parts requirements. Often, these parts are considered in isolation from production parts, but in reality they need to go through many of the same steps to get from the supplier to the customer.

Spares are ultimately delivered to customers at locations across the country. Inventory is typically held by the lead contractor to satisfy demand. While this demand can be forecasted to some extent based on past history and maintenance cycles, it is largely unpredictable, leading to safety stock at the warehouse. As customer demand comes in, product is shipped from this warehouse. The process is shown below:

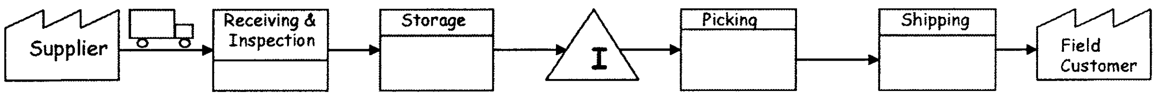


Figure 2: Representative spares handling process

This process is similar to the production process, with the exception that kitting is not required following the pick, and is instead replaced by a shipping process.

The analogous process to point-of-use storage for spares is to have parts shipped directly from the supplier to the customer as needed, bypassing the entire receiving, warehousing, and shipping process. There are strategic and technical barriers to achieving this for all parts. As significant business comes through the management of spares, the lead contractor has an incentive to maintain ownership of the process. By cutting themselves out of the process by linking the supplier with the customer, this business may be lost. On the technical side, the need for quality inspection of some parts is one driver to flowing all spares through the lead contractor facility. Another is the ability to consolidate and manage inventory for customers without the use of electronic systems linking the inventories of many suppliers. Whether for strategic or technical reasons, it is unlikely that all spares will be shipped directly from suppliers to the customer without passing through the lead contractor's facility, even if quality is certified by the supplier. A realistic assessment of this direct shipping option needs to be made jointly by production and spares personnel before plans are made for the overall handling process.

In the likely case where many spares will need to be received, stored, and shipped to customers via a central facility, it is important to consider the costs of this process in conjunction with the requirements for production. The fixed costs associated with setting up appropriate facilities may make it advantageous not to set up two separate operations, instead combining facilities into one operation. In addition to this fixed cost, there are two other cost advantages to sharing facilities. First, there is the potential for pooling spares and production inventory, resulting in overall inventory reductions. Second, collocation of facilities will reduce the transaction costs associated with shipping parts between warehouses.

When a spare parts warehouse can be consolidated with a production parts warehouse, there is additional incentive to choose the central storage approach over the point-of-use storage approach. However, the organizational barriers to accomplishing this can be substantial. This will be addressed in more detail in section 6 of this thesis.

3.4.3 Conclusions Regarding Warehousing

As companies approach just in time inventory levels, it is becoming possible to employ point-of-use storage systems. These do offer several advantages, most notably the ability to easily see and track inventory on the shop floor. However, there are several good reasons to avoid this type of system. Beyond the difficulty of controlling and managing inventory, two issues indicate that central storage is usually a better option. First, outsourcing of materials management responsibilities is only a strong option under the central storage approach. Second, central storage offers the possibility of including spares and production handling under one roof. For these reasons, the central storage option will continue to be the most compelling choice for most programs into the future.

4. Outsourcing Decision Making Process

4.1 Aerospace Make/Buy Decisions

4.1.1 A Continuum of options

The outsourcing discussion initially centered on make/buy decisions for part fabrication, with many in the aerospace industry outsourcing non-core manufacturing to suppliers. The lead contractors for commercial and defense aircraft instead choose to focus on assembly, design, and system integration. However, in many cases it may make sense to outsource some of this integration activity to suppliers as well. In fact, one can imagine a continuum of outsourcing decisions, starting from the simple make/buy decision for a part, going all the way to having suppliers provide complete subsections of the aircraft. At each stage, the supplier is taking on more of the integration activity previously reserved for the lead contractor, and increasing responsibility for handling parts.

Parts made in-house. Vertical integration	Supplier-made parts delivered individually	Suppliers provide their own parts in kits	Suppliers integrate other supplier parts in kits	Suppliers integrate parts and manage subtier suppliers	Suppliers provide complete subassemblies to aircraft

INCREASED SUPPLIER PARTS HANDLING RESPONSIBILITY →

Most manufacturers have established make/buy decision processes at the part level. A typical process would consist of both strategic and tactical questions that need to be answered in order to determine the fate of any given part. On the strategic level, a company needs to determine its internal competencies and decide what businesses it will or will not pursue. As an example, an aerospace integrator may choose categorically not to participate in the development of avionics, but for strategic reasons choose to always make certain aircraft structures in-house. These strategic reasons may include the need to develop or maintain competencies for the future, the desire to control key process technology to avoid its loss to competitors or suppliers, or the need to allocate fixed investments required for other programs over a broader base of work.

Parts not defined as "always make" or "always buy" need to be subjected to a more rigorous analysis to determine if they should be outsourced. This analysis includes the appraisal of candidate supplier capabilities, internal process capabilities, a risk assessment, and finally a cost analysis to determine the impact of outsourcing on the cost of the finished product. The result of this analysis is the determination of which parts should be outsourced and which should be kept in house.

This approach can be extended beyond the part level to include integrated assemblies or even modular subsections of an aircraft. At each level, the stakes become higher as the value of the work increases. Similarly, the analysis becomes more complex, requiring the evaluation of multiple suppliers and risks. The cost analysis for such a decision requires not only part by part costing, but the assessment of overhead costs required for managing multiple suppliers, materials handling, assembly, and significant fixed investment costs for assembly.

4.2 Materials Management Outsourcing

In aerospace assembly, the outsourcing of materials management responsibility, including logistics, purchasing, and production control responsibility, represents a decision on the chart above lying between outsourcing individual parts and outsourcing entire assemblies. This outsourcing of materials management can happen in three ways. Most simply, the task of handling and packaging all materials can be transferred to a third party that takes on all of the logistics functions normally handled by the internal materials management department. This replaces the function in a straightforward outsourcing decision.

Rather than outsourcing this entire function to one service provider, this responsibility can be distributed to a number of different suppliers. In this second case, an existing supplier can take on that responsibility for one or more kits, handling only parts handling and logistics for that kit and delivering a full kit of parts only when needed. This can be done without taking on supplier management, design, or assembly responsibilities. The third way that materials management responsibilities are outsourced is when suppliers take on more responsibility for assembly integration. In this case, they necessarily take on the required materials management responsibility associated with procuring and handling the parts that make up that assembly.

In section one of this report, the general criteria for strategic make/buy decisions were discussed, and it was concluded that in most cases materials management outsourcing is not an "always make" function. However, a process is still needed to determine if and how the function should be outsourced given the potential options. All three cases above require a similar thought process to determine if and to whom responsibility should be outsourced. The following section outlines this decision making process, calling out specific details that are unique to the materials management make/buy decision.

4.3 Decision making process

Before a specific materials management outsourcing decision can be made, three separate sets of decisions have been made for the project. First, it is necessary to make a strategic decision if the materials handling function is either an "always buy" or "always make" function for the organization. In the majority of cases, it will not be "always make", and if it is determined to be "always buy", the timing of the transfer to a third party and selection of supplier is still important.

Second, the process assumes that make/buy decisions have been made at the part level in accordance with existing processes within the organization. This process will result in part suppliers being chosen based on capabilities, past performance, and cost. Another consideration in this process may be the benefit of consolidating work within one kit with a single supplier. This will facilitate any future transfer of parts integration responsibility to a single supplier. However, this only makes sense within the context of ongoing supplier consolidation activities, and should not contradict decisions made on the basis of supplier capabilities. This make/buy and supplier selection activity helps to establish the requirements for materials handling for a project or set of projects.

Finally, the assembly process needs to be broken down into installations. This is to make sure that the proposed kit is a logical work package for the mechanics on the shop floor. In some cases, switching parts between kits may make the logistics of kitting easier, but make things more difficult on the shop floor. In general, the kits are there to serve the needs of the mechanics, and if the parts are not a logical work package then any supplier kitting effort will be counterproductive. This assignment of parts to kits is critical in establishing the quantity and type of kits that will need to be handled by the materials management organization.

Once these questions have been answered, yielding a set of parts, suppliers, and installations broken down by kit, a series of questions need to be answered to determine whether a supplier should assist in the kitting and integration activity. The questions that need to be asked depend on the type of outsourcing being considered. While a combination of approaches could be contemplated, this analysis considers the three options mentioned above – the outsourcing of the entire materials management function, the outsourcing of kit integration and delivery responsibility to a parts supplier, and the outsourcing of kit integration and sub-tier supplier management to a parts supplier. These scenarios are described below.

4.4 Outsourcing Scenarios

4.4.1 Outsourcing of entire materials management function

In the first scenario, the entire materials management function is outsourced to a third party logistics provider (3PL). This 3PL acts as an integrator of parts into kits that can be presented to the mechanic. High level supplier management functions would still be handled by the manufacturer, but all logistics functions, including the scheduling of deliveries, receiving, storage, and internal transportation would be handled by the 3PL. This allows for the elimination of overhead as well as variable costs associated with internal materials management.

4.4.2 Outsourcing of individual kit integration and delivery to an existing parts supplier

This is referred to as "supplier kitting". In this case, the supplier is concerned with kitting and shipping parts in a package that is suitable for delivery directly to the line. This can either be only their own parts or a combination of their own parts and parts that have been delivered to them by other suppliers. If only the supplier's own parts are kitted, then upon arrival at the factory these pre-packaged parts will be integrated with parts from other suppliers into complete kits before being sent on to the line. In this case, the assumption is that all suppliers are still managed by the lead contractor, but that one "main" supplier in each kit is selected to integrate parts, either due to capability, location, or the quantity or cost of the parts they provide to the kit.

4.4.3 Outsourcing of integration and sub-tier supplier management to an existing parts supplier

This is close to having suppliers deliver completed subassemblies, which in turn would be a logical next step if assembly constraints allow it. This reduces not only materials handling costs within the organization, but also shifts much of the burden for quality management, supplier management, and procurement to the integrating supplier. This creates additional questions for the organization, as the functions involved go beyond just materials handling, but touch on procurement, quality, and even design.

4.5 Key Process Steps

In each scenario, three major areas need to be addressed. These are:

1. The development of internal processes for managing the coordination of the new system
2. The assessment of supplier capabilities – both the supplier of logistics services and the impact of part supplier capabilities on the outsourcing decision
3. The evaluation of the cost impact of the decision

The following sections address these areas as applied to each of the three outsourcing possibilities described above. The figure below represents the overall process, showing the major steps involved. The steps outlined in the dashed box only apply to the scenarios where responsibility for individual carts or assemblies is distributed to existing suppliers. The other steps apply to all three of the scenarios.

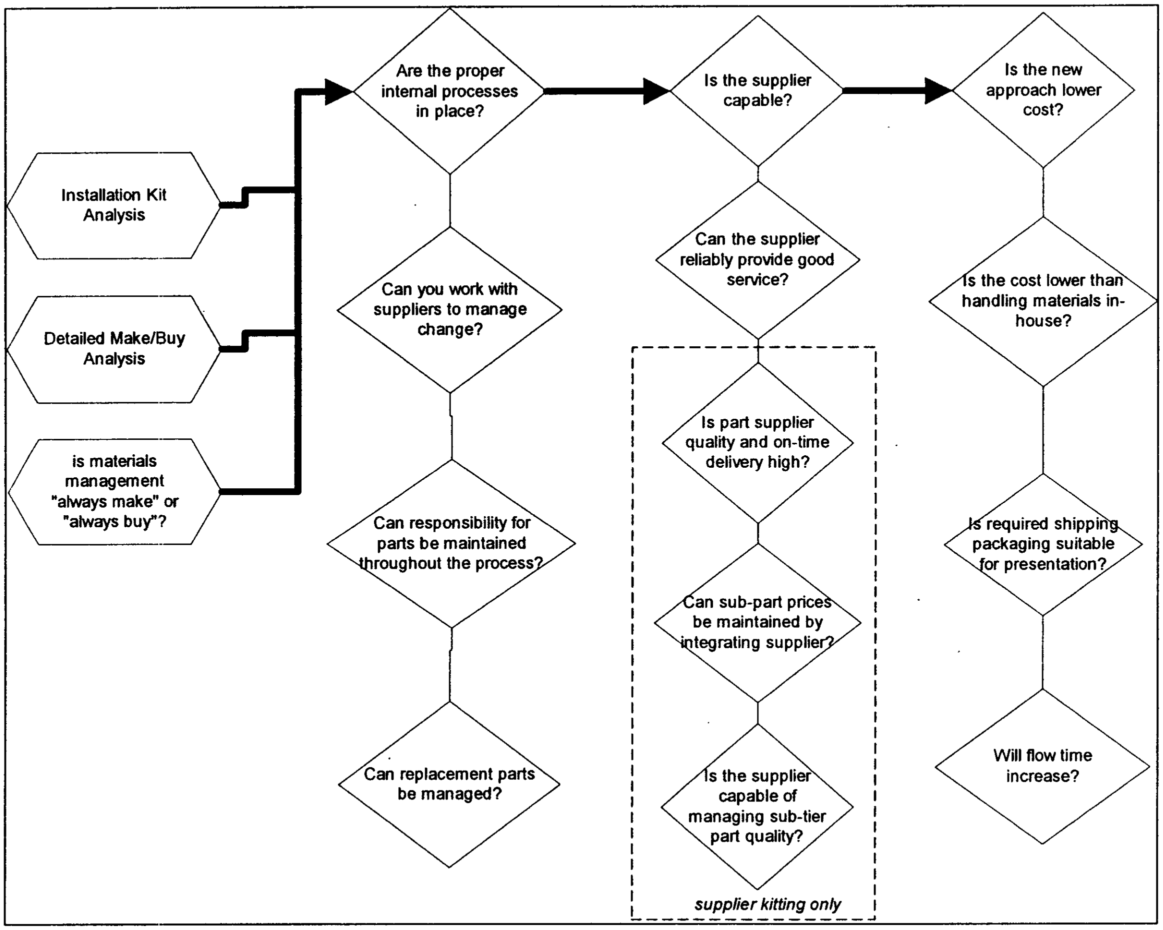


Figure 3: Decision making flowchart for outsourcing materials management

4.5.1 Internal process development

Are processes in place to work closely with suppliers to manage changes?

The outsourcing of materials management responsibility requires new processes to effectively coordinate manufacturing and design changes. The kits into which parts are consolidated serve an important function in implementing continuous improvement on the factory floor. As mechanics and supervisors recognize opportunities to improve the assembly process, changes to kit configuration need to be made, leading to changes that need to be implemented by the materials management organization. When that organization is located inside of the factory, operations and materials management personnel, possibly working within the same functional organization, can work closely together to rapidly implement changes in cart design, frequently without formal documentation. When the kitting function is outsourced, new processes need to be established to manage those changes between the assembler and materials management provider.

Creating an effective change management system is critical to the success of any aerospace program. In the case of materials management, there are several ways that such a system could be implemented. The most obvious is to create formal documentation for each kit cart and treat it as part of the bill of materials. Changes to carts can be proposed by the manufacturing team and communicated electronically to the materials management supplier to create any new carts and start building up the carts to the updated configuration. If complex carts need to be designed and it is more effective, an internal engineering department could create them and deliver them to the materials management department for use.

As an alternative, the materials management supplier and operations team could implement changes more informally. This could be done by having the teams work closely together, much as would be the case with an internal materials management team. This may be difficult to do in some labor environments, where outside contractors may not be welcome or even allowed inside of the union factory. Another less formal solution, sometimes referred to as "soft kitting", would not include kit carts in the bill of materials, but rather let the physical carts themselves serve as the organization for the kitting operation. Updates to the physical carts, which should be clearly labeled, would show the supplier changes to the configurations. This allows the personnel designing carts to convey information back to the supplier as quickly as they can re-label the carts. Regardless of the system used, the process needs to be robust enough to avoid confusion and mistakes in delivering the parts, but fast enough that it does not discourage continuous improvement on the factory floor.

When a single cart is being outsourced to an existing parts supplier, rather than the entire process, it is wise to consider the stability of that cart design. In this case, the implementation of changes may be more difficult, as configuring carts in such a way that individual parts move from cart to cart may result in a change of parts flow from one supplier to another. Changes to this cart may require more oversight and documentation than equivalent changes done within the company or within one supplier. Additional issues come up if management of sub-tier suppliers is also delegated to an existing parts supplier. In this case, parts may require close oversight from the lead contractor's engineering team. This will be especially true early in the project, when design changes and quality issues will be more frequent. In this case, separating the team from the sub-tier supplier by using an intermediate supplier to manage parts will result in added complexity in communication. This suggests that more outsourcing of parts and kits should occur in a program as the design becomes more stable.

Can responsibility for parts be maintained throughout the process?

In the case where sub-tier suppliers are not managed by the integrating supplier, complications in assigning responsibility for quality issues may occur. For example, if damage is found at final assembly, the cause of the damage will now need to be assigned between three parties, not just two. This will require additional quality checks or procedures which may add cost to the process.

Similarly, responsibility for providing pull signals or schedules throughout the process needs to be clear. This can range from having the lead contractor provide all information through a web-based tracking system to having fully decentralized control through kanban systems that propagate through the main supplier to sub-tier suppliers. In either case, this process needs to be clearly established to enable success.

Can replacement parts be managed?

A process needs to be put in place to manage replacement parts that are needed due to quality defects, scrap created in the assembly process, or design changes. When inventory is not locally available, the replacement parts need to be delivered quickly outside of the normal kit delivery process. Soft kitting is one such process that would help to facilitate this by organizing parts without tying the kit to a formal bill of materials. Other processes tailored to the needs of the organization can be created, and will depend on internal tracking systems, the amount of inventory kept on hand, and typical part replacement times. The key is to allow replacement parts to be delivered to the line as quickly as would be possible using internal resources, without making entire kits of parts obsolete as replacement parts are "borrowed" from them.

4.5.2 Supplier capability

Can the supplier reliably provide good service?

Suppliers to the aerospace industry are rated on a range of metrics to evaluate their quality. Typical supplier metrics include part quality, on-time delivery, cost, and softer metrics reflecting responsiveness. Contractors providing materials management services also need to be evaluated on metrics other than cost. These metrics may include average dock to factory floor flow time, average turnaround time on filling requests for full carts, or percent of carts delivered full and on time. These metrics need to be designed to not penalize the supplier for factors outside of their control, while creating incentives to provide more rapid and higher quality service. When a supplier is only handling and kitting parts but not supervising sub-tier suppliers or handling the scheduling of part delivery, they can not be held responsible for inventory levels held in storage. However, if they are given responsibility for scheduling and the management of sub-tier deliveries, inventory turns may be a reasonable metric to include in a supplier evaluation. Ideally, these metrics would be well defined and the performance evaluated before transferring materials handling work to a supplier. This will help to reduce the risk of outsourcing.

Is individual supplier quality and on-time delivery high?

This applies only to the outsourcing of individual carts. When an existing parts supplier kits parts, quality and delivery problems for the parts in that kit can be compounded. One of the challenges with supplier-kitted materials is that kits are often held up if any one part is late or missing. When a supplier is asked to kit a number of parts, the likelihood that an entire kit is held up by one bad part goes up exponentially. What would have been a shortage of one part at the factory becomes a shortage of many parts, making it more difficult to find solutions for working around the shortage on the factory floor. This makes it essential to have very high quality and on-time delivery for parts being kitted by outside suppliers.

This assumes that the entire cart is held up given that one part is delayed or of poor quality. The alternative, where an incomplete cart may be sent, creates its own set of problems, but represents a better alternative if processes are in place to handle replacement parts. The shipping of incomplete carts requires a set of processes designed to handle the tracking and expediting of missing parts while still making use of the existing parts. However, even in this situation it is not worth the effort to pursue supplier kitting if quality is not high, as the advantages of supplier kitted materials largely disappear if the supplier can not deliver complete packages. Time would be better spent on improving performance than creating integrated kits.

When all materials management is outsourced, the same problem can occur if good processes are not in place for managing the transfer of incomplete carts from the supplier to the factory floor. However, a close working relationship with the one supplier should make it easier to manage than handling problems with a number of different integrating suppliers.

Can sub-tier part prices be maintained by the supplier?

This applies only to when supplier management responsibility is transferred to the integrating supplier. By outsourcing full carts to integrating suppliers, including the management of those suppliers, the lead contractor may be relinquishing pricing power with sub-tier suppliers. This is especially true for smaller components used in large number throughout the aircraft but in different kits. In this case, volume is split over several integrating suppliers, perhaps resulting in a smaller volume discount for each. Sub-tier part prices may also increase because the integrating supplier does little other business with the sub-tier business, while the lead contractor engages the sub-tier supplier on many projects. In either case, the increased parts prices must be considered as part of the overall cost of supplier kitting. If additional procedures or agreements are made to transfer the original pricing power to the integrating suppliers, the administrative cost of such agreements should be considered.

Is the supplier capable of managing sub-tier supplier quality?

This applies only when supplier management has been outsourced to the integrating supplier. When supplier management responsibilities are outsourced, it may be the case that the supplier does not have the required experience for managing sub-tier suppliers of the kitted parts. This goes beyond simply having the capability for receiving and putting parts into kits. Robust supplier quality processes, pull systems, and supplier management skills should all be present in the organization if they are to consistently deliver completed, high quality kits at a low cost. Additionally, the financial health of the integrating supplier should be looked at in even greater detail, as more is now at risk if the supplier fails.

4.5.3 Cost & Logistics

Are costs lower than handling materials in-house?

This will depend on the capabilities of the supplier and internal cost savings. In some cases, the supplier will not be better at kitting and integrating parts than the lead contractor. Any supplier kitting project should compare the price charged by the supplier for the kitting service to the internal costs incurred for kitting the same material. For this reason, a cost model that allows the organization to assess the cost of handling materials and integrating kits is essential to making sound decisions. As more responsibility is outsourced to the supplier, additional costs will be shifted from the integrator to the supplier. These indirect costs, such as purchasing, quality oversight, and production control, need to be considered as well. However, as more functions are outsourced to suppliers, it becomes more unlikely that the supplier will have strong capabilities in all of the required areas, and the prices charged by suppliers for those functions will likely go up. A model for analyzing internal costs is described in detail in Section 5.

Is the required shipping packaging suitable for presentation to the mechanic?

Some parts require special packaging for shipping, but can be put into kit carts at the line once they have been transported to the factory. If shipping packaging is not suitable for presentation to the mechanic, then parts kitted outside the factory will essentially be kitted twice – once to be shipped, and again after being unwrapped and repackaged for presentation to the mechanic. This can happen anytime that shipping methods require special packaging, whether it is through a third party logistics provider or an existing supplier. When the materials management function is onsite, small transportation carts can be used to safely transport parts without bulky packaging. When the function is moved offsite, it is more likely that special packaging will be needed to permit the use of trucks to bring parts to the line. If kit integration is done outside the factory, it should not be necessary to unpack and prepare the parts again for the mechanic. If that is not possible, the parts should just be sent in separately and put into final kits at the line.

It may be possible to design and purchase packaging that meets both shipping and presentation needs, but this will likely be more expensive than using more generic packaging and kitting solutions. Other packaging cost tradeoffs will exist as well. For example, reusable containers will result in lower disposal costs for packaging waste and potentially lower long-term packaging costs, but the cost of container design or return shipment of the container to the supplier may be prohibitive. Any increase in packaging costs, whether through recurring purchasing or return shipping, needs to be considered as part of the cost analysis for supplier kitting.

Will flow time increase?

The process of sending parts through an intermediate supplier may add to the flow time of getting those parts to the line. The sub-tier supplier parts will now need to be sent to the integrating supplier, then on to the factory. If the integrating supplier is located far from the factory, this may add transportation time to the system when compared to having the integration activity take place at the factory. Similarly, any administrative complications that result from sending the parts through an intermediate step may add to the flow time. Any increase in time should be considered and traded off against the benefits of outsourcing.

4.6 Summary

This process described in this section steps through the questions that should be posed to an organization considering the outsourcing of materials management to a new provider. While cost savings are an important component in the analysis, and are addressed in detail in the next section, a decision based solely on cost considerations may overlook critical shortcomings in either internal processes or supplier capabilities. Hidden costs of outsourcing such as part price changes, increased packaging needs, and flow time increases could also be overlooked. This process drives the company to consider, at least qualitatively, the factors other than direct cost that impact the outsourcing decision. If any of these factors are deemed to be significant, a more quantitative analysis can be done to weigh the shortcomings against any cost savings. Alternatively, the outsourcing decision could be delayed until the proper conditions can be put in place internally and at the supplier.

5. Cost Model to Support Decision Making Process

5.1 Cost Model Rationale

The process described in section 4 is designed to make sure that strategic questions that are hard to capture in a cost model are not overlooked when deciding whether to outsource a kit to suppliers. When considering such a decision, it is possible that the strategic elements line up in favor of outsourcing. However, placing these kits with suppliers may result in increased costs. Unfortunately, it can be difficult to evaluate the true costs involved with the materials management process, especially when only part of the process is being outsourced. In order to make a rational decision about whether or not to outsource integration of a kit to a supplier, one needs to understand the internal costs of creating the kit. This can then be compared to the price provided by a supplier to provide the same service.

Generally speaking, it is not guaranteed that a supplier will have more effective materials handling capabilities than the internal organization. Some third-party logistics providers may not have experience in handling and kitting aircraft parts and their significant documentation and storage requirements[17]. In the case of supplier kitting, where existing suppliers are used to handle specific parts or sections of the aircraft, it is less likely to find a strong kitting and handling capability. Unlike a third-party logistics provider, parts handling and integration may or may not be a core competency of the supplier's organization. In fact, in most cases a lead contractor will have equal or greater experience in parts handling and kit integration due to their long history in the business. For this reason, it is critical to compare internal cost savings to external bids before making the conclusion that outsourcing parts handling to suppliers will result in savings for the program. This is relatively straightforward to do when entire functions are being outsourced. In this case, the entire budget for that department can be eliminated. It is more difficult to do when only an incremental part of the function's workload is

[17] Many aircraft parts need to be tracked by serial number due to safety regulations or the documentation requirements of government property. Specific rules require that some inventory be held separately depending on owner, part type, or inspection status. This can create additional burdens on logistics providers.

outsourced, as in the case of supplier kitting. It is this situation that is addressed by the cost model here.

5.2 Cost Model Overview

The cost model described below breaks down each of the tasks involved with creating and delivering a complete kit of parts for the mechanic. Actual costs of the operation will vary by company and site, but the framework remains the same. The goal is to assess the internal costs of kitting.

The model makes generalizations about the costs of putting together kits, basically assuming that all parts are equal in handling and overhead cost. In reality, some parts will be more costly to handle than others, or may require much more oversight. However, the goal is get a rapid assessment of costs for a given kit. This will allow the lead contractor to make a judgment if further analysis is required. For most cases, costs will be significantly higher or lower than a supplier's bid. In the borderline cases, a more detailed analysis can be done, but it is likely that more strategic concerns would drive the decision.

Different companies will have different cost functions to determine the cost of individual transactions. As a first order approximation, it is assumed throughout this analysis that costs are proportional to the number of transactions performed for a given task *i*, where

$$k_i = \frac{C_i}{N_i}$$

Here, C is the total variable cost for providing a function *i*, N is the total number of transactions performed by that function, and k represents the cost per transaction. Once the proportional constant k has been determined, the total cost for kit *j* can be represented by

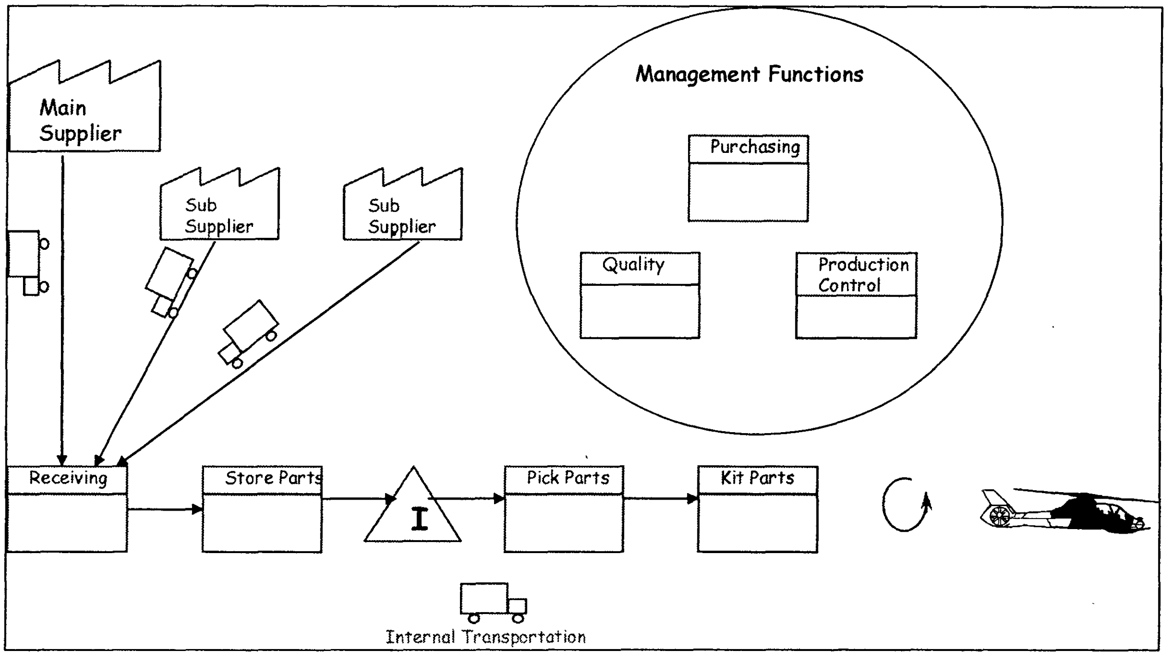
$$K_j = \sum_i k_i n_i$$

where K is the total cost for the kit, reflecting the sum of *i* functional tasks required to create that kit.

The core concept is that any marginal change to the work required by a function will result in a roughly proportional change in total costs. In reality, costs may be non-linear or be characterized by a significant fixed cost that creates a substantial intercept to any proportionality constant relating cost to the number of transactions. As larger percentages of work are outsourced, these non-linearities will become more significant in estimating the cost savings of outsourcing that incremental amount of work. In this case, a more detailed analysis will need to be performed that looks at the specifics of the situation.

Inputs to the model are the kit composition, part cost, part lot sizes, internal labor costs, and the internal transaction history. The output is the cost of kitting, broken down by functional area. These calculations are detailed below, and a sample printout of this spreadsheet is included in the Appendix of this report.

5.3 Breakdown of Cost by Function



5.3.1 Direct Kitting Costs

The most obvious costs of kitting come from the physical handling and integration of parts as they pass from the supplier to the factory floor. When a supplier is kitting parts but not managing sub-tier suppliers, these are the only costs that are transferred from the lead contractor to the supplier. As can be seen in the process map above, this involves four key steps:

Receiving

This is where parts are received into the factory, typically triggering the payment process and closing out orders with suppliers. The receipt of parts is acknowledged by entering information into a computer system. Some cursory inspection of the parts may occur at this stage to ensure that the indicated type and quantity of part are in the shipped package. The parts are then tagged to be transferred to the next location. For the parts being considered here, this is the warehouse.

The cost of receiving should be proportional to the number of transactions performed. In the case of receiving, this is equivalent to the number of packages that must be physically handled and scanned into the system. The fewer parts received, the fewer transactions are required, resulting in fewer workers required to physically move boxes, inspect their contents, and enter the parts into the computer system. For this reason, the receiving cost of a kit will be proportional to the number of receiving transactions required to produce it.

A cost per transaction can be determined by determining the labor budget for the receiving area per year and dividing by the total number of transactions. The next step is to determine the number of receiving transactions per kit. Since many parts will have lot sizes greater than one, a single receiving transaction may supply a part for many kits. This is taken into account in the cost model. The number of receiving transactions per kit is multiplied by the cost per transaction to yield a receiving cost per kit.

Storage

In the majority of cases, parts will be put into storage for a period of time before being withdrawn for use at the line. This requires physically taking the parts and putting them into the warehouse.

Again, this cost should be proportional to the number of transactions performed. In this case, this should be the same as the number of lots placed into storage. Assuming that all parts are put into storage at least for some period of time, the number of storage transactions should be equal to the number of receiving transactions. Following the same process, a cost per storage transaction is determined by dividing annual labor costs by the annual number of transactions, and is then multiplied by the number of storage transactions per kit to yield a storage cost per kit.

Pick and Kit

When a kit is requested by the assembly line, this triggers a "pick and kit" operation. Picking a part means to retrieve a part from the warehouse. The part is then placed into the kit. Each part is picked until the kit is full, at which point the kit is sent to the warehouse. These operations are considered together because in practice they are usually collocated and performed by the same personnel.

The cost should be proportional to the number of transactions performed. In this case, a single transaction is considered to be the picking of a part number for a kit. If more than one part is required (say, 20 screws), this is considered to be one transaction. Using this methodology, each kit will have "pick and kit" transactions equal to the number of part numbers in the kit.

The cost per pick and kit transaction is determined by dividing the annual labor costs by the annual number of transactions. This is then multiplied by the number of "pick and kit" transactions per kit to yield a "pick and kit" cost per kit.

Transportation

Internal transportation costs can vary widely from factory to factory depending on the type of transportation required (truck, forklift, golf cart) and the distance to be covered between the warehouse, and assembly line. For this reason costs are broken down in the same fashion as the other operations. For simplicity, only transportation of a complete kit between the warehouse and the line and back is considered. The transportation cost between receiving and the warehouse is assumed to be part of the labor charges of those respective departments. Depending on how internal accounts are tracked, it may make sense to split out that transportation separately.

In this case, total transportation costs are divided by the number of kits transported to yield a transportation cost per kit.

5.3.2 Indirect Costs

When a supplier takes on the task of managing sub-tier suppliers, a number of indirect costs are transferred from the lead contractor to the supplier. These costs are more difficult to estimate than the direct costs. For this analysis, it is assumed that costs are proportional to the number of parts tracked. However, in reality the setup of the lead contractor's processes may make these costs highly nonlinear with a large fixed component. Again, this model is meant as a guide that can quickly determine the magnitude of costs saved by transferring kitting to a supplier. More detailed analyses can be undertaken as necessary for individual kit.

Inventory

When a supplier is asked to supply complete kits to the line, any inventory that would normally be kept in the lead contractor's warehouse is shifted to the supplier. While this inventory may be kept on the books of the lead contractor, with the supplier only providing logistics services, it is more likely that the supplier would be asked to take on the inventory so as to provide a built-in incentive for the supplier to provide efficient management of incoming parts. The average inventory sent to the supplier is found by either looking at historical inventory levels, or in the case where there is no part usage history, by examining the lot order size based on A/B/C inventory levels. In this case, assuming little safety stock is kept, this is found by subtracting one from a part's lot size and then dividing by two, yielding the average cycle stock added to the process by not using a single piece flow. This inventory is then multiplied by the cost of each part to determine a total dollar value of inventory resulting from doing internal kitting, and in turn by a holding charge for inventory to determine the inventory cost of kitting.

Purchasing

The purchasing function is largely made up of buyers who are responsible for placing orders with suppliers. The buyer also serves as the primary contact point between the lead contractor and suppliers. In this model, the assumption is that the amount of buyers needed is proportional to the number of purchase orders that need to be overseen.

The annual labor cost is divided by the number of purchase orders handled per year to determine the average cost per purchase order. This is then multiplied by the number of purchase orders avoided by having one supplier handle all of the sub-tier supplier orders.

The result is the purchasing cost per year per kit. This is then divided by the number of kits per year to give the purchasing cost per kit.

Quality

This model assumes that quality is managed through a process validation method. In this case, the amount of quality personnel should be proportional to the number of parts that need to be tracked, assuming that all parts require equal attention. Of course, this assumption is not true, but on the whole this methodology should yield an average cost per part, which should be somewhat evened out over the contents of an entire kit.

The annual quality cost is divided by the quantity of part numbers tracked by the quality organization. This is then multiplied by the quantity of part numbers that will not need to be tracked if the supplier handles this responsibility instead. This number is the quality cost per year per kit. This is then divided by the number of kits per year to give the quality cost per kit.

Production Control

Production control personnel are responsible for scheduling parts to the factory and line. When a supplier takes over responsibility for an entire kit, the production control representative only needs to track one kit rather than an entire set of parts. It can be assumed that the amount of production control personnel is proportional to the number of parts tracked.

In this case, the annual cost for production control is divided by the number of parts tracked to get a transaction cost for each part tracked. In this case, the total quantity of parts rather than part numbers is used. This is then multiplied by the number of parts that no longer need to be tracked when moving to supplier kitting. This gives the cost per kit for production control work.

Space

When fewer parts need to be handled, it is possible to reduce the size of the facilities used to handle parts. While most of this facility cost is in actuality fixed, each part that is not received or kitted reduces the need for that space and makes it more likely that it will be possible to transfer to a smaller space. For this reason, space is still included as a variable cost of kitting.

Space for receiving, kitting, and storage needs to be considered. If any of this space, particularly storage space, is already included as part of the holding cost of inventory for the incoming parts, it should not be double-counted here. The total number of square feet used is divided by the number of transactions handled to yield a square footage per transaction. This is then multiplied by the annual cost per square foot of space and divided by the number of transactions per year to yield a cost per transaction. This is then multiplied by the number of transactions per kit to give the cost of space required per kit.

5.4 Example of Kit Analysis

The Comanche helicopter program was a good example of a program making extensive use of kitting to aid the process of final assembly. During the summer of 2003, over 100 kits were being designed for this new program, with a wide range of part quantities and types in each kit, depending on the assembly requirements at that particular location. As an example of this decision making process, one such kit is described in detail below. The part descriptions have been hidden and the values have been normalized. In many cases where exact values for data were not yet known due to the early stage of the program, they have been estimated.

5.4.1 Kit Description

The kit under consideration consisted of 15 different part numbers from 12 different suppliers. One component made up the majority of the part value of the entire kit. The rest of the parts were members of the same subsystem, and were necessary to complete assembly in the area around the part installation. Pre-assembly of the parts before arriving at final assembly was not possible given the space and precedence constraints of the installation process.

The breakdown of the cart is shown below:

Parts	Quantity per kit	Cost Each
part1	1	16000
part2	2	1500
part3	10	60
part4	1	2800
part5	1	130000
part6	4	500
part7	1	6500
part8	20	40
part9	10	50
part10	5	140
part11	4	500
part12	1	5000
part13	1	6500
part14	25	15
part15	1	12500

Figure 4: Part Descriptions for sample cart

In this case, only one part number was made in-house. The remainder of parts was purchased from suppliers located throughout the US.

5.4.2 Perform strategic make/buy analysis

The Comanche program was considering the outsourcing of individual carts to outside suppliers. A separate analysis would have looked at all of the carts in the system and the transactions required to determine if the outsourcing of the entire materials management process was warranted. However, such an analysis was not being undertaken at the time of this project. In the case of this example, the prime candidate for kit integration was the supplier of part 5, the highest value part in the cart.

Given this context, the basis for the strategic analysis is in place. An assembly analysis has been performed to determine the best way to organize parts into kits, defining the kit cart described above. Make/buy decisions have been made on the part level and appropriate suppliers have been chosen. Finally, materials management has been determined to be a "sometimes make" type of process, where individual carts can be outsourced if appropriate.

The first question addresses the existence of processes to manage kit outsourcing. In this case, the relationship with the supplier was very good. The supplier had recently attended a supplier workshop targeted at identifying opportunities to work more closely together to identify supply chain savings. In addition, the supplier had worked with the organization on previous programs with good results. It was very promising that the processes could be put into place to communicate effectively with the supplier to manage changes in the cart design, and the supplier was willing to devote resources to establishing this process. With respect to other internal processes, it had not been determined yet how responsibility for parts would be passed on throughout the process, or how replacement parts for kits would be managed. However, these issues had been identified and were being addressed on other pilot programs within Boeing and Sikorsky.

With respect to capabilities, the supplier in question had performed well in the past on the part level. However, there was some question as to whether the supplier had the capabilities to manage a number of parts from different suppliers and package them into kits to be delivered to Comanche. The supplier had no experience with part kitting and integration for customers, but was willing to bid on such a project. In this case, without any track record of deliveries to date, it was hard to estimate the quality and on-time delivery for other parts in the kit.

In this example, the case to have the supplier manage sub-tier suppliers was not very strong. While the supplier had experience managing input part quality for their own parts, the parts they would be asked to oversee in this case were very different than the materials with which they had experience. It was likely that Comanche quality personnel would still need to be heavily involved in monitoring part quality of the sub-tier suppliers. Also, it was clear that sub-part prices that could be negotiated by

Comanche would likely be hard for the new integrator to negotiate, given the smaller scale of the new integrator and the lack of any relationship with the sub-tier suppliers.

The result of this was that the supplier was not a good candidate at this time to manage the entire kit and sub-tier suppliers, providing all supplier management, procurement, and quality control functions. However, given the willingness to work closely with Comanche to develop processes for kit integration, the supplier may be a good candidate for managing the physical part handling. While there was uncertainty over the supplier capabilities, it was worth investigating the potential cost savings of outsourcing this activity. This involved having the supplier put together a bid on the work involved and comparing this bid with internal costs.

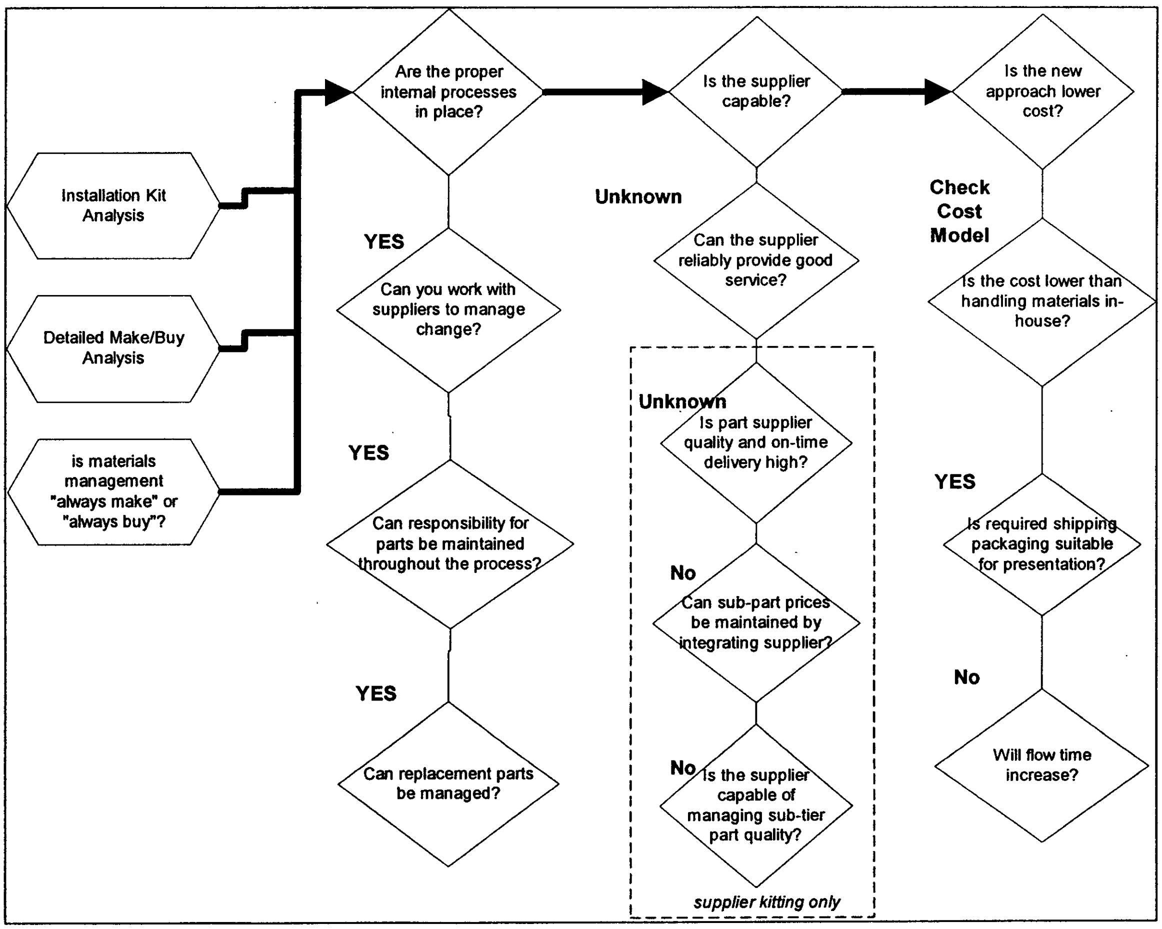


Figure 5: Flowchart applied to one sample kit on Comanche program

5.4.3 Analyze direct kit costs

The direct costs of the kits include each of the processes that actually touch the parts between the supplier and the line. These steps are receiving, storage, pick & kit, and transportation. Each of these processes is characterized in the cost model by a function relating the number of transactions performed to the total cost incurred in the process. In the example above, the first step is to determine the number of transactions performed in bringing one kit of parts from the supplier to the line.

For several processes, the number of transactions will depend on the lot size of the part. For example, if only one part is used in a kit, but a lot size of ten is received at any one time, then only 0.1 receiving transactions are performed for that part per kit. Therefore, the first step is to gather data on the lot sizes for each of the parts in question. In the example above, lot sizing has been estimated by applying an A/B/C lot sizing methodology to the parts in the question. This lot sizing, based on having 2 weeks of A inventory, 6 weeks of B inventory, and 12 weeks of C inventory while using a roll rate of one aircraft per week, yields the following results for lot sizes:

Parts	Quantity per kit	Cost Each	A/B/C	lot size
part1	1	16000	A	2
part2	2	1500	B	12
part3	10	60	C	120
part4	1	2800	B	6
part5	1	130000	A	2
part6	4	500	C	48
part7	1	6500	B	6
part8	20	40	C	240
part9	10	50	C	120
part10	5	140	C	60
part11	4	500	B	24
part12	1	5000	A	2
part13	1	6500	A	2
part14	25	15	C	300
part15	1	12500	A	2

Figure 6: Lot sizes for example cart of parts

Given this information, the relationships outlined in the cost model description are applied to determine the number of transactions per cart for each part in question.

Parts	avg receiving transactions/cart	avg storage transactions	avg pick/kit transactions	avg tranport transactions
part1	0.50	0.50	1	0.50
part2	0.17	0.17	1	0.17
part3	0.08	0.08	1	0.08
part4	0.17	0.17	1	0.17
part5	0.50	0.50	1	0.50
part6	0.08	0.08	1	0.08
part7	0.17	0.17	1	0.17
part8	0.08	0.08	1	0.08
part9	0.08	0.08	1	0.08
part10	0.08	0.08	1	0.08
part11	0.17	0.17	1	0.17
part12	0.50	0.50	1	0.50
part13	0.50	0.50	1	0.50
part14	0.08	0.08	1	0.08
part15	0.50	0.50	1	0.50

Figure 7: Transactions for each cart

In turn, costs are estimated for each transaction using the overall costs of each unit and the total number of transactions processed per year. A linear relationship between cost and transactions performed is assumed in this example. For this example, the following numbers have been used based on the throughput of transactions required to handle the build of 100 aircraft per year with 10,000 parts per aircraft, although actual costs may be quite different in each organization. This assumes that the materials management organization is handling parts for multiple programs, one of which has a build rate of one per week. The other programs represent the remainder of the 100 aircraft being built at the same facility.

This results in the following table of costs for each function in the kit:

Variable Kitting Costs - EXAMPLE				
days/year	230			
hours/day	8			
# of parts per kit	15			
# of kits (aircraft) per year	100			
	Receiving	Storage	Picking & Kitting	Internal Transport
# transactions per year	200,000	200,000	333,333	200,000
direct labor cost/year				
# people	16	5	25	6
average labor $/hour	$ 20	$ 20	$ 20	$ 20
$/transaction	$ 2.94	$ 0.92	$ 2.76	$ 1.10
# transactions/kit	3.67	3.67	15	3.67
$/kit	$ 10.79	$ 3.37	$ 41.40	$ 4.05
Total Cart Cost	$ 59.62			

Transaction volumes are representative of a factory building 100 aircraft per year with 10,000 parts each
Labor data is not representative of any particular program

Figure 8: Overall function and kit cart costs

It can be inferred that if only the materials handling of parts is outsourced, with the prime contractor retaining ownership of inventory, purchasing, quality, and production control functions, then the internal cost savings for outsourcing this cart of parts will be approximately $60 per aircraft, or $6000 per year. This should be compared to the bids and costs of alternative suppliers.

5.4.4 Analyze indirect kit costs

Indirect kit costs include the cost of holding inventory, processing procurement transactions, overseeing supplier quality, and coordinating the scheduling and delivery of parts. Under different outsourcing scenarios, some or all of these costs may be outsourced to a supplier.

For this particular example, the decision flowchart suggested that given the supplier's inexperience in kitting and sub-tier management, outsourcing indirect management tasks such as managing supplier quality and procurement would not make sense without a significant expansion of supplier capabilities. If outsourcing were to occur at this level, a very similar process to the direct kitting model would be applied as described in the previous section.

5.4.5 Compare to supplier bids and negotiate

At this point, the organization is at a point where it can compare internal cost savings with the bids of suppliers. In this example, an incremental cost of $60 per kit is taken on by the organization when direct materials management is kept in-house. It is important at this point to obtain a bid from the prospective supplier. This may be included as part of a long-term agreement to supply parts for the project, or may be addressed separately from negotiations for individual part supply. Three outcomes are likely from this process.

First, the supplier bid may be much lower than the internal cost, or they may agree to take on the responsibility for free in return for growing their own capabilities or locking in long-term business with the organization. In this case, a pilot program should be pursued to establish the process and verify that it makes sense to fully outsource the cart activities. A second scenario would have the supplier either refusing to bid or agreeing to supply the services only at a rate much higher than the internal costs. This would indicate that the individual cart outsourcing should not be pursued. Other suppliers may be evaluated as alternatives, or the cart should be kept in-house.

Finally, the supplier bid may be close to the internal cost savings. In this case, strategic considerations will dominate the decision. It may be desirable to enhance the supplier relationship or to create better internal capabilities for managing outsourcing. Also, an investment may be made with the hope that future costs will decrease as the supplier capabilities improve. In any case, the understanding of internal costs is still critical in providing a benchmark for trading off cost savings with strategic considerations.

6. Conclusions and Reflections

6.1 Materials Management Outsourcing

Within the aerospace industry, the materials management function is a good candidate for outsourcing. Outside logistics providers have the advantage of being able to focus on one clear task. Additionally, these providers can have significant economies of scope, managing parts for many different clients, giving them an advantage in the use of capital equipment and space. In some cases, the ability to work in a non-union environment can give an outside logistics provider a strong cost advantage over unionized factories using more expensive internal employees to provide materials management support. Given robust processes for coordinating work, companies specializing in logistics can provide a high level of service to the aerospace integrator at a low cost. There will be a trend towards increased outsourcing of this function in the future. The exceptions to this trend will largely be in factories with non-union employees, where one warehouse provides support to several programs. In these cases, the cost advantage of outsourcing may be outweighed by the closer coordination and flexibility possible when managing an internal team.

While increased outsourcing seems likely, the decision making process described in section 4 should still be applied to determine if such an outsourcing decision makes sense at any given time. Concerns about the processes needed to manage a new logistics provider need to be addressed. Additionally, a company needs to identify a suitable partner to manage their materials management needs. The failure to properly apply the tests described in the process above could cause disruptions to part supply and reliability, crippling a program.

Cost is another concern that needs to be considered in this outsourcing decision. This cost assessment serves as the final input to the decision making process described in section 4. When the entire materials management process is outsourced, costs are relatively easy to gather. In some cases, it may be desirable to outsource individual kits to suppliers. In these cases, it is important to have a methodology in place for estimating the incremental internal cost savings of sending the cart integration to the supplier. The cost model described in section 5 provides the framework for making a comparison to outside bids, allowing a rational choice to be made on a cart by cart basis.

Beyond these processes, it is critical to consider the outsourcing process in the context of the broader supply chain initiatives being made within the organization. Inventory reduction made possible by the implementation of the best practices described in section 2 will have an impact on materials management requirements. For example, the warehousing strategy selected by a company will depend on inventory needs and the ability to manage within pull systems. This strategy selection in turn will have an impact on the ability to readily outsource materials management to outside suppliers.

Similarly, the important role of spare parts in the aerospace industry should not be ignored in designing the proper system. Unlike some other industries, aircraft integrators keep close control of spare part inventories, especially for defense programs. The requirements for managing these parts calls for systems very similar to production parts. If the materials management system is optimized separately for production parts and spare parts, an opportunity for significant cost reduction may be missed. The need for managing spares as well as production parts may lead to different results in outsourcing decisions, both in terms of what to outsource and what capabilities are required in a potential logistics supplier.

While apparently straightforward, the process of making these decisions becomes more complicated within the framework of a typical aerospace organization. Most of the processes described in this thesis, from the implementation of pull systems to the outsourcing of materials management, require the mobilization and coordination of several if not many functions, both within and outside the organization. The following discussion addresses the difficulty involved with this task, and offers some suggestions on ways to make such changes easier to execute.

6.2 Organizational Barriers

It is difficult to make changes to processes within a complex aerospace environment. Projects are typically very complex, project teams are large, and the penalty for a failure is very high. Existing processes are further cemented by the organizational structures that have been created to manage these complex projects. Traditionally, the challenge has been to create processes that work across functional silos within the organization to create better performance. With the increasing use of joint ventures, partner-type supplier relationships, and extensive outsourcing, external organizational barriers also play a key role in preventing the implementation of new ideas that may unlock value within the extended aerospace enterprise.

6.2.1 Internal

Purchasing, materials management, quality, operations, and spare parts management are just some of the internal functions that are required to deliver aircraft to a customer. Within these functions there is a further breakdown of responsibility by sub-function. For example, materials management may be broken into receiving, warehousing, and transportation teams. This allows employees to be managed in reasonably sized teams that can focus within their business specialty. Performance metrics are often assigned to each team to align team performance with company goals.

These functions are often overlapped in a matrix organization with new projects, where each employee works for both a function and a specific project team. This allows the support teams to be sensitive to the needs of the program, and hopefully the customer as well. This program focus should also help to facilitate the creation of solutions that cut across functional lines.

When trying to implement changes in something like the company's supply chain, these functional lines become very important in framing the decision making process. Unaligned incentives, a lack of trust between parties, and politics work to prevent the implementation of what on paper may look like the best solution. Three examples related to this thesis serve as an illustration of this.

The first and simplest example to understand is the outsourcing of the materials management system, and may apply to any situation where a function is outsourced. If after going through the process described in this thesis, it is determined that the materials management system should be outsourced, there will still be substantial resistance to the change. Not only does this outsourcing imply the loss of many jobs within the organization, it also results in a loss of prestige for a previously important organization. Many managers within the function, even those who will be keeping their positions, will not support the change. This behavior also would call into question the impartiality of the analysis done during the process of determining whether or not to outsource to begin with. This suggests that such an outsourcing process needs to happen at a high level, and will frequently be made without substantial input from the function to be outsourced.

The second example of how organizational barriers complicate a desirable change process is the potential merger of a spares and production warehouse, along with responsibility for the management of inventory planning. Merging the spares and production warehouse for a program can provide benefits of reduced facilities costs, lower transaction costs due to a lack of transfers between warehouses, and even an inventory reduction made possible by pooling parts between the two customer demand streams. Close coordination of inventory planning could also lead to better planning with suppliers, avoiding spikes in demand that come from uncoordinated orders for the same part that is used for both production builds and spares. Unfortunately, these parts are usually managed by two distinct organizations. One is focused on meeting metrics associated with smooth production, while the other is focused on meeting customer demand for spares.

When shortages do occur on either side, both groups will accuse the other of undisciplined planning that leads to having to borrow from the other side, leading to a lack of trust between the two organizations. Beyond this, physical infrastructures and processes for handling spare parts separately from production parts makes it even more difficult to implement changes. Merging the two functions would require strong leadership from above, coupled with the creation of new processes for planning, managing, and distributing parts. Because this process is so difficult, it may be easier to try the new system in a pilot case before trying to change the entire organization.

A third example is the general problem of inventory reduction. The solution to this problem requires input from the entire organization, including operations, purchasing, sales, and engineering. Implementing pull systems or min/max systems that can help with inventory reduction requires that the entire organization rally behind the new initiative. It can not be led by only one function. It is for this reason that companies like Boeing and United Technologies extensively hold cross-functional workshops, sometimes called Accelerated Improvement Workshops or Kaizen events, to create new processes within the organization. At these workshops, high level employees from multiple functions gather to create new processes and solutions that cut across the entire organization, often using value stream maps or similar tools to help see the entire process.

The difficulty of making such changes suggests that the pace of change will be somewhat slow. However, it is essential that companies try to stay ahead of the competition by using the most efficient processes that they can. Many of these changes will require the input of employees through cross-functional workshops or other processes. In all of these cases, strong leadership needs to play a strong role in creating the environment for change. Most of the time, this leadership needs to come from a position that is above the functional silos that may resist the change. In any case, an analysis that suggests a change will be beneficial to the organization is only the start of the process of actually improving performance.

6.2.2 External

Stakeholders outside of the internal organization also play a role in creating and implementing change initiatives. In many cases, it is impossible for an organization to implement changes without significant help from suppliers, customers, and partners. As programs become more complex and companies become more focused, this coordination across company lines is becoming more important.

The RAH-66 Comanche program was typical of many new programs in that it involved a web of partnerships that were critical to achieving good performance. The lead contractor was Boeing Sikorsky Aircraft, a joint venture between Boeing Rotorcraft and Sikorsky Aircraft. The program office was comprised of Boeing, Sikorsky, and US Army personnel, all working together to make the program a success. While final assembly was located at a Sikorsky facility in Bridgeport, Connecticut, the rear of the aircraft was assembled at a Boeing facility in Philadelphia. Boeing and Sikorsky each managed half of the supplier value. The joint team tried to keep a program focus and create a "Comanche" way of doing things. However, key support for the project came from within the Boeing and Sikorsky functional organizations. Each side used different systems for supply chain management, from quality to purchasing to materials management. This meant that two parallel processes were being used to bring materials from suppliers to the line. This prevented the companies from sharing and adopting each other's best practices, and resulted in the companies operating with a more arm's length relationship than would be the case if all activities were under one roof.

The main joint venture was just one more supplier/partner relationship that needed to be managed to yield improvements in the supply chain. Beyond the joint venture level, both companies were also pursuing initiatives with key suppliers to streamline ordering, packaging, and kitting processes. Forging strong partnerships with these suppliers was key to making progress. For example, min-max systems could not simply be switched on for suppliers, but needed to be implemented slowly to ensure that supplier needs were met. In another case, outside suppliers were brought into an internal Kaizen event, leading to a number of new suggestions for improving performance. The effective implementation of changes increasingly involves working beyond the internal organization and with external partners.

6.2.3 Keys to implementation

Given the need to coordinate both internally and externally, several keys to successful change emerge. First, strong leadership is needed at a high level in order to create change. This may not require direct supervision of the change, but at least the mandate to make it happen. To actually implement the change, the use of cross-functional workshops to break down functional silos is an important tool. This allows the big picture goals to be embraced despite local biases, and aligns the team, at least temporarily, to achieve the goal of improvement. Similarly, some roles within the organization may be better defined in new ways. For example, in some plants Boeing is adopting a role of planner/buyer, avoiding the need for separate planning and buying functions, and allowing one person to see and manage more of the process. Finally, it is important to recognize the importance of the functional organizations in driving changes. While focusing on programs can help to achieve some goals, the overall results need to be embedded into company systems and processes. Otherwise, programs will each operate as their own company. While some factory improvements can operate on the program level, high-level supply chain changes need to involve the functional level, coordinating not only the stakeholders in one program, but also the entire organization.

6.3 Reflection

The process of creating an aircraft is a complex task, and the multitude of processes required to do so successfully would take a lifetime to learn. The educational experience of spending six months on site at the RAH-66 Comanche program office was invaluable to me in understanding this complexity and the difficulty in improving existing processes. This task was even more difficult given the joint venture system being used by Comanche. I personally found it humbling to discover the limits of technical analysis within such an environment. However, there were some key lessons that I took away from the experience.

First, it is critical to work from the right place in the organization. In my case, the major leverage to be made on supply chain issues was within the functional organizations located at Sikorsky headquarters in Stratford, Connecticut and Boeing Rotorcraft headquarters in Philadelphia. Unfortunately, I was located on the program team in Bridgeport. While having the program support made it easier to gain access to multiple sites at both Boeing and Sikorsky, it made it difficult to plug into the teams working on supply chain improvements in either site.

Second, given the scope of the organizations involved in the project, it should have been clear to me earlier that significant efforts were underway at the functional level to improve performance. Having been brought in by the program, it was not clear where the real efforts were being made to improve the supply chain and how I could help most. It took some time to find a topic for my project – supplier kitting and the topic of materials management outsourcing – that was beneficial to the functional organizations as well as the project team.

Third, sitting at the intersection of two large aircraft integrators gave me the advantage of seeing two different companies with different cultures. It was interesting to observe that while both companies' participation in the Lean Aerospace Initiative and similar consortiums had led to the adoption of similar business processes, both companies still had their own management approaches, organizational structures, and atmosphere. However, both were very successful. It was an indication that there is more than one way to do things to be successful.

Finally, I regretted learning this past February that the Comanche program had been canceled. I was impressed with the team's effort to deliver a successful program in the face of considerable technical barriers, schedule pressure, and political opposition to the program. My project was focused on decisions that would be impacting the program performance in three to five years, while most people in the office were scrambling to meet near-term deadlines that may impact the existence of the program. I felt a little out of the loop sometimes during the project, but just being on site was enough for me to appreciate the scope of the challenge the team was facing. I was particularly impressed by the leadership team at Comanche, who maintained a relentlessly upbeat and focused message throughout the duration of my project. One of the most positive things I'll take from my internship was the example set by that team.

Bibliography

Ansari, Abdolhossein, and B Modarress. Just-in-time purchasing, Collier McMillan, 1990.

"Boeing goes abroad for 7E7 work", *Flight International,* November 2003.

"Boeing's Secret: Did the aircraft giant exploit accounting rules to conceal a huge factory snafu?" *Business Week,* May 20, 2002.

Boyson, Sandor et al. Logistics and the extended enterprise: benchmarks and best practices for the manufacturing professional, Wiley, 1999.

Bozdogan, Kirk. "Lean Aerospace Initiative supplier management assessment tool: version 1.0", March 2004.

Bruck, Felix. "Make versus buy: the wrong decisions cost", *McKinsey Quarterly,* 1995, Number 1.

Cutcher-Gershenfeld, Joel et al. "Customer and supplier integration across the supply chain, lean aircraft initiative implementation workshop", March 1999.

"Delivering the promise - Joint Strike Fighter", *Flight International*, November 2003.

Dyer JH, Cho DS, Chu Wujin. "Strategic supplier segmentation: the next best practice in supply chain management", *California Management Review*, 40 (2), Winter 1998.

Fine, Charles H. Clockspeed: winning industry control in the age of temporary advantage, Perseus, 1998.

Fine, Charles, and Daniel Whitney. "Is the make-buy decision process a core competence?", April 1996.

Gansler JS. "Incentive strategies for defense acquisitions", Department of Defense Memorandum, Jan 2001.

Juergens, Bob. "Exostar: e-procurement and supply chain integration", Presentation to Lean Aerospace Initiative workshop: Building Internet-Enabled Integrated Value Networks, January 30, 2001.

Lynch, Clifford. Logistics Outsourcing: A Management Guide, Council of Logistics Management, 2000.

Nahmias, Steven. Production and Operations Analysis, McGraw-Hill, 2001.

Quinn, James, and Frederick Hilmer. "Strategic outsourcing", *McKinsey Quarterly*, 2000, Number 2.

Ronen, Boaz, and Dan Trietsch. "A decision support system for purchasing management of large projects", *Operations Research,* 36(6), Nov-Dec 1988.

"Seattle dreaming: Boeing has set itself some hefty challenges to launching its proposed 7E7 Dreamliner, its first all-new program in 13 years", *Air Transport World*, 40(12), December 2003.

Shapiro, Jeremy. "An overview of supplier rating, certification, and selection systems in the defense aircraft industry", MIT Paper, March 1995.