Evaluating Cost-Reduction Alternatives and Low-Cost Sourcing Opportunities for Aerospace Castings and Forgings

By

Amber J. Obermoller

S.B. Environmental Engineering, Massachusetts Institute of Technology (2002)

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

Master of Business Administration
Master of Science in Materials Science and Engineering

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Signature of Author____
Department of Materials Science and Engineering &
MIT Sloan School of Management
May 9, 2008

Certified by_____
Thomas Eagar, Thesis Supervisor
Professor of Materials Engineering and Engineering Systems

Certified by_____
Charles Fine, Thesis Supervisor
Chrysler LFM Professor of Management and Engineering Systems

Certified by_____
Jonathan Byrnes, Thesis Supervisor
Senior Lecturer, Engineering Systems Division

Accepted by_____
Samuel Allen, POSCO Professor of Physical Metallurgy
Chair, Departmental Committee on Graduate Students

Accepted by_____
Debbie Berechman
Executive Director of MBA Program, MIT Sloan School of Management

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ABSTRACT

As companies continue to outsource large portions of their manufacturing, managing costs in the supply chain is increasingly important in reducing overall costs and remaining competitive. Low-cost sourcing has become an increasingly prevalent way for companies to reduce total costs. This thesis develops a methodology for evaluating cost-reduction alternatives and low-cost sourcing opportunities.

This thesis is intended to provide procurement managers with assistance in making informed and well-thought out decisions regarding cost-reduction and low-cost sourcing choices. Six criteria are established to compare cost-reduction alternatives and evaluate the fit of an alternative with the company's supply chain strategy. A framework is developed to aid procurement managers in evaluating low-cost sourcing opportunities. This framework involves the utilization of filters to screen parts, countries, and companies for fit with the supply chain strategy. A model that can provide recommended sourcing locations is developed to evaluate domestic low-cost sourcing options.

Thesis Supervisor: Thomas Eagar
Title: Professor of Materials Engineering and Engineering Systems

Thesis Supervisor: Charles Fine
Title: Chrysler LFM Professor of Management and Engineering Systems

Thesis Supervisor: Jonathan Byrnes
Title: Senior Lecturer, Engineering Systems Division

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Table of Contents

1. Introduction

The purpose of this thesis is to provide a framework for procurement managers to evaluate ways of decreasing supply chain costs, specifically focusing on low-cost sourcing opportunities. This thesis is based on an internship conducted within the procurement department at Pratt & Whitney (P&W), a division of United Technologies Corporation (UTC), in East Hartford, Connecticut. This internship was performed as a collaborative effort between P&W, the Leaders for Manufacturing program at the Massachusetts Institute of Technology, and the author.

This study looks specifically at reducing costs for castings and forgings within the jet engine manufacturing industry, which was the basis of the internship at P&W. While this is the primary focus of the study, the intent is to provide an evaluation framework which may be applied to the sourcing of high-quality parts in other companies and industries as well.

There are two primary goals of this thesis. The first goal is to provide a broad discussion of cost-reduction opportunities to aid managers in recognizing potential opportunities and risks. The second goal is to develop a framework that procurement managers can use to evaluate this information.

1.1. Project Motivation

The business model of the jet engine industry makes controlling costs imperative to P&W's success. The industry operates under a loss-leader business model, where engines are generally sold for a loss and profits are made in the aftermarket from selling spare parts and servicing engines. An increase in costs can either be passed through as an increase in engine price or it can be absorbed internally and regained through aftermarket sales. Neither of these options is attractive. An increase in the engine cost would increase the price of P&W engines relative to their competitors, which could result in a loss of sales. Absorbing the extra costs increases the time required to break even financially on an engine sale, which reduces the attractiveness of business opportunities and could also result in a loss of sales.

Since profits in this industry come primarily in the aftermarket, they correlate positively with the number of engines currently in the field. When increasing costs result in a decrease in engines sold today, future profits are negatively affected. Those profits are necessary to balance losses from selling engines. Without those profits, a company might compensate by selling fewer engines to improve its financial statement. This creates a reinforcing negative spiral which can best be stopped by reducing costs.

Many companies today are increasing the amount of work being outsourced, with the result that a greater percentage of total cost is being spent on supply chain as opposed to in-house manufacturing. Throughout this thesis, supply chain costs and procurement costs are defined as the total costs required to purchase and receive a part, including, but not limited to, costs relating to materials, value-added processing, shipping, and quality inspections. As P&W's supply chain becomes larger, more global, and

a greater percentage of total cost, more attention is being given to reducing costs within the supply chain. Reducing costs through supply chain management involves trying to affect costs that are not completely in the control of the company. This presents challenges to procurement managers as they try to adapt previous cost-reduction efforts to this new arena where the parties involved are not part of the same company and may have different end goals. Supply chain costs are rising within the jet engine manufacturing industry, and thus greater attention is being placed on addressing these challenges.

It should be noted that there are definitely areas other than a company's supply chain where costs can be reduced. Areas where P&W and other companies can and are working to reduce costs include manufacturing and assembly processes, engineering and design processes, and labor and overhead costs. A company should also consider whether it is more cost effective to produce a part in-house or to outsource it. The scope of this thesis is on reducing costs in the supply chain, which is just one aspect of a cost-reduction strategy.

1.2. Thesis Overview

This thesis begins by broadly discussing factors affecting sourcing within the jet engine manufacturing industry and then gradually narrows the focus of the evaluation. This thesis is structured as follows: Section 2 provides an overview of relevant sourcing factors within the jet engine manufacturing industry, UTC, and P&W and provides a literature review on this topic. Section 3 discusses key procurement factors to consider in developing a supply chain strategy that is consistent with the overall goals of the company. Section 4 investigates four possible ways to reduce costs within the supply chain and provides an initial evaluation framework for determining which cost-reduction techniques would be appropriate for a company for further evaluation. Section 5 provides a framework for a more in-depth evaluation of cost-reduction alternatives, utilizing low-cost sourcing as an example and evaluating three low-cost sourcing alternatives to determine whether these options are viable for a company. Section 6 evaluates how to make specific sourcing decisions once low-cost sourcing has been decided upon. Section 7 summarizes the main ideas in this paper.

This thesis is intended to assist managers in making sourcing decisions by taking them through the process from industry considerations to specific sourcing locations. Managers can use this as a guideline for evaluating cost-reduction alternatives specific to their company and industry.

2. Industry and Company Background

This thesis evaluates procurement factors that are directly related to the current state of the jet engine manufacturing industry and P&W, then generalizes a few of those factors. This section provides background information on the industry and company as it is relevant to this evaluation. The analysis focuses on castings and forgings as stated and as appropriate. This section also includes a review of relevant literature pertaining to this thesis and discusses how this thesis fits in with existing research.

2.1. Porter's Five Forces Industry Analysis

This section provides an industry analysis conducted based on the framework developed by Michael E. Porter in 1979 and further developed in 1980. This framework, commonly called Porter's five forces analysis, is based on the idea that there are five factors that influence an industry's profitability and that should therefore influence a company's strategy. These five forces are: the threat of new entrants, the bargaining power of suppliers, the availability of product substitutes, the bargaining power of buyers, and the struggle between competitors. Evaluating the industry and a company's position in relation to these forces allows for the determination of potential profits in the industry and for the company. It highlights the company's strengths and weaknesses. According to the analysis, a company should develop its strategy based on maximizing its advantage and minimizing its vulnerability in these five areas.[1] The concepts discussed within this section are relevant throughout this thesis when evaluating cost-reduction alternatives.

For the purposes of the analysis within this thesis, the industry is defined as the final manufacturers of large jet engines. There are three primary players within this industry: P&W, General Electric, and Rolls Royce. This analysis evaluates this industry in regard to each of the five forces and is summarized in Table 1. Based on this analysis, the industry is moderately attractive.

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[1] Porter, Michael E. Competitive Strategy: Techniques for Analyzing Industries and Competitors. New York: The FreePress, 1980.

Force	Threat Level	Main Points
New Entrants	LOW	- High capital requirements. - Long payback period. - Strong brand identification and customer relationships. - Technical knowledge and integration processes required. - Highly regulated.
Suppliers	LOW - HIGH	- Competition exists for low-end parts. - Limited number of suppliers capable of technology and quality requirements for complex and capital-intensive parts. - Switching costs can be high. - Little threat of forward integration of suppliers. - Real threat of backwards integration of industry, competitors.
Substitutes	LOW	- No close substitutes.
Buyers	MODERATE	- Buyers include airplane manufacturers (e.g., Boeing, Airbus) and end users (e.g., Delta Airlines, United States Department of Defense). - End users have power to select engine for given airplane. - High switching cost once installed - low aftermarket buyer power. - Little threat of forward or backward integration.
Competitors	HIGH	- Competitors are primarily General Electric and Rolls Royce. - Loss-leader business model makes recouping development costs a key priority. - Strong brand identification and customer relationships. - Competition for development funding is intense. - Product differentiation on quality is becoming more difficult.

Table 1: Porter's Five Forces Analysis of the Large Jet Engine Manufacturing Industry

2.1.1. New Entrants

New entrants into a market affect the industry by attempting to gain market share away from incumbents and by influencing the available profits. The two primary deterrents of new entrants are barriers to entry and the anticipated reaction from incumbents.[2] This section investigates the threat that new entrants currently possess to the industry. Based on this evaluation the threat to industry incumbents from new entrants is low.

There are six basic barriers to entry. These are:

1. Economies of scale;
2. Product differentiation;
3. Capital requirements;

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[2] Porter, Michael E. "How Competitive Forces Shape Strategy." Harvard Business Review 57.2 (1979): 137-145. 21 Jan. 2008 http://web.ebscohost.com.libproxy.mit.edu/ehost/pdf?vid=5&hid=107&sid=ba6e32c0-71fd-4dbc-bab3-1d1a24b6b66b%40sessionmgr102.

4. Cost disadvantages independent of size;
5. Access to distribution channels; and
6. Government policies.[3]

Economies of scale create one barrier to entering the industry. Platforms from one engine can often be used as a basis for a new engine, decreasing design and development costs and timeframes. Economies of scale have some effect in manufacturing costs, but as many processes in this industry are low volume, these gains can be small.

There are various ways to differentiate a product from that of competitors. Technology and quality are two key differentiating factors in the industry. It is becoming increasingly difficult for manufacturers to differentiate their products on these aspects. Jet engine manufacturers are outsourcing a greater percentage of their work than they did historically. Forgings and castings are a good example of this. These products require a high degree of specialization, thus the number of potential suppliers is limited and competing engine manufacturers share a good portion of their supply chain. Suppliers' costs are thus similar between competitors, making it difficult to gain a competitive advantage on cost. The shared supply chain also creates a technology sharing point that could be available to new entrants. Another common technology sharing point is joint ventures between competitors. In order to win work, the three big engine manufacturers team together in joint ventures. Any technology a company uses for one of these joint ventures is shared with competitors. Thus it is difficult to maintain any technology advance for long, and price once again becomes the determining factor. Customers are increasingly seeing jet engines as interchangeable, with price being the only difference.[4]

Brand identification does represent one area where product differentiation would likely present a major barrier to entry. Jet engines are highly complex, high profile products. Customers like to go with a name and a technology they trust. In many cases development and design costs are shared with or subsidized by the customer. This is unlikely to happen with a new entrant until they have proven their design and development capabilities. The knowledge of how to design a jet engine could be purchased, but it would be difficult to develop the necessary integration amongst suppliers, customers, and internal development groups.

A large amount of capital is required in order to design and develop an engine. With the loss-leader business model, incumbents have an absolute capital barrier advantage in having revenue from an installed engine base to offset losses from designing, developing, and selling new engines. The

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[3] Porter, Michael E. Competitive Strategy: Techniques for Analyzing Industries and Competitors. New York: The FreePress, 1980.
[4] Soucy, Arthur L. De-Commoditizing the Commercial Jet Engine Business. MIT Sloan School of Management. 2007. 14 Jan. 2008 <http://dspace.mit.edu/bitstream/1721.1/39517/1/173961831.pdf>.

development and testing cycle for an engine takes from six to ten years when starting from an existing platform, and longer if a company were starting from scratch. Generally a company does not start making money on an engine model until approximately 14 years after beginning development. The large amount of money required combined with the long payback period makes financing a barrier to entry.

The main cost disadvantages unrelated to size are experience and learning curves. As a part is made, the workers become more efficient at the manufacturing process due to repetition, and the company becomes better at making that part through trial and error and experience. These improvements are generally referred to as learning and experience curves, respectively.[5] New entrants would not be able to replicate these improvements, thus this is a barrier to entry.

Access to the distribution channels in this industry would depend on having a relationship with the airplane manufacturers. Jet engines are highly integrated into the airplanes in which they are placed. A new entrant would have to work with the airplane manufacturers to integrate their product. Because of the high complexity of the product and existing relationships with incumbents, the airplane manufacturers have little incentive to assist a new entrant.

The industry is under strict government regulation, and any incoming players require government approvals. Governments with current engine manufacturers are likely to try to protect the incumbents and impede entry into the industry. Any new entrants would need to become familiar with all of the government regulations and procedures for approvals.

Assuming a new company did try to enter the market, the reaction of the incumbents would be swift and fierce. With small profit margins, low volumes, and the loss-leader business model, the companies currently in this industry will fight to protect their status and market share. The three incumbents are all diversified companies with deep pockets that are capable of putting up a good fight.

The threat to the industry incumbents from new entrants is low. High barriers to entry exist in terms of economies of scale, customer relationships and brand identification, the amount of capital required, the timeline required to achieve profitability, and the need for government approvals. It would be difficult for any new companies to enter the market.

2.1.2. Suppliers

The bargaining power of suppliers can affect the industry by shifting profits from the engine manufacturers to the suppliers. Suppliers gain bargaining power when there are few supplier companies, when suppliers have unique or differentiated products with high switching costs, and when the purchasing

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[5] Porter, Michael E. Competitive Strategy: Techniques for Analyzing Industries and Competitors. New York: The FreePress, 1980.

company is not an important customer to the supplier.[6] In this industry, the threat from supplier bargaining power ranges from low to high depending on the parts and suppliers in question. Competition exists for low-end parts, which make up the minority of spend, but the majority of pieces. Suppliers of these parts have low bargaining power. Suppliers of the more complex and capital-intensive parts tend to have high supplier bargaining power and present a high threat to the industry.

A few key suppliers have a lot of power in this industry, especially in castings and forgings. The high technical requirements and high level of quality required limit the number of capable suppliers. Of the few suppliers capable of making complex aerospace castings and forgings for the western world, most of these suppliers differentiate themselves by technical capabilities or size of parts and occupy a niche of the market. The vertical integration of certain suppliers provides an additional source of supplier power. For example, Precision Castparts Corporation (PCC), one of P&W's major castings suppliers, is vertically integrated into areas such as alloy production, the manufacture of investment casting wax blends, and the melting and processing of special alloys.[7] This is beneficial in providing customers with a wide range of options, but detrimental in that it provides these suppliers with some control over the market, thus further limiting true competition. In some instances there is only one supplier capable of making a part. These suppliers have positioned themselves so that they do not compete on price. The amount of competition that can be created between suppliers is minimal. This is augmented by the fact that these companies have a wide array of customers, and the engine manufacturers do not necessarily constitute a large percentage of work for these suppliers. All aerospace customers constituted only 53% of PCC's sales in the 2007 fiscal year. General Electric was the only customer to account for more than 10% of total sales, at 11.4%.[8] The amount of leverage that can be used against key suppliers is limited.

Castings and forgings constitute a large percentage of cost in the industry. For castings, switching costs are relatively high in the form of tooling costs and efficiencies lost from learning and experience curves. Additional inventory required during transitions adds to switching costs. If a supplier has previously (and recently) made a part, the switching costs are greatly reduced.

There is currently little threat of suppliers' forward integration, but a real threat of industry backward integration. Casting and forging suppliers lack the knowledge to make large jet engines. The casting and forging industry is more profitable, so forward integration is likely not attractive. This does

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[6] Porter, Michael E. "How Competitive Forces Shape Strategy." Harvard Business Review 57.2 (1979): 137-145. 21 Jan. 2008 http://web.ebscohost.com.libproxy.mit.edu/ehost/pdf?vid=5&hid=107&sid=ba6e32c0-71fd-4dbc-bab3-1d1a24b6b66b%40sessionmgr102.

[7] Form 10-K: Precision Castparts Corp.: Annual Report. Securities and Exchange Commission. 31 May 2007. 28 Feb. 2008 <http://www.precast.com/PCC/SEC_Filings.asp>.

[8] Form 10-K: Precision Castparts Corp.: Annual Report. Securities and Exchange Commission. 31 May 2007. 28 Feb. 2008 <http://www.precast.com/PCC/SEC_Filings.asp>.

make backwards integration of the jet engine manufacturers more attractive. Rolls Royce has always maintained their own casting foundry, and both General Electric and P&W have recently purchased foundries. Joint ventures are also being set up between industry players and casting and forging suppliers.

The threat of supplier's forward integration could be increased in the future as companies in this industry share more technical information with low-cost suppliers. Some of these suppliers are vertically integrated and currently make or historically made jet engines. If these suppliers acquired enough technology and information on western design and manufacturing requirements and techniques, the suppliers might be able to eventually compete by manufacturing the entire engine. Given that these suppliers are in low-cost areas, the suppliers would likely be able to establish a competitive advantage based on price and begin to erode the lower end of the market. This would enable the suppliers to gain additional manufacturing information and experience to the point where the entire market could potentially be at risk.

The bargaining power of suppliers in this industry ranges from low to high. For some key parts there are a small number of capable suppliers, with differentiated products, whose fortunes are not dependent on the industry. The incumbents have minimal leverage in this situation.

Because the industry has high supplier bargaining power, dealing with or lessening this power should be a focus for incumbents. Incumbents could attempt to limit the volume of product needed from suppliers with high bargaining power in the design phase. However, this could have the added effect of making the incumbent a less important customer to the supplier since the incumbent's percentage of the supplier's work would decrease. This could make it more difficult dealing with the parts remaining at that supplier, as the supplier would have less incentive to maintain a good relationship by being price competitive and having on-time deliveries. An incumbent could try to integrate backwards into the areas where suppliers have high bargaining power. An incumbent could try to increase the number of suppliers in the industry by developing low-cost suppliers, which would provide the incumbents with leverage for dealing with current suppliers. Incumbents could try to create a more readily available substitute for the supplier's product. The incumbent companies should develop strategies such as these internally in order to deal with the high bargaining power of suppliers, knowing that this is a weakness for them in the industry.

2.1.3. Substitutes

Substitutes for a product can negatively affect the industry by providing a cheaper alternative. This can, in effect, set a maximum price that manufacturers can charge for a product. Substitutes limit the

prices and profits of an industry. Substitutes are products that provide the same function as the product within the industry.[9] In this industry, the threat from substitutes is low.

There are no close substitutes to a large jet engine. The complexity of a jet engine far exceeds that of automotive or other engines. No other products provide the same function as a jet engine. Therefore the threat from substitutes is low.

2.1.4. Buyers

The bargaining power of buyers can affect the industry by allowing the buyer to set prices and limit profits. Buyers tend to have high bargaining power when there are few buyers in the industry and these buyers tend to purchase in large quantities. Buyer power is increased when products are undifferentiated, when products constitute a significant fraction of the buyer's total costs, when buyers have low profits, when the product is unimportant to the buyer's final product quality, and when the product does not save the buyer money. In this industry the threat from the bargaining power of buyers is moderate.

Buyers in this industry include both the aircraft manufacturers (primarily Boeing or Airbus) and the end users of the aircraft (e.g., Delta Airlines and the United States Department of Defense). There are a relatively limited number of both types of buyers, and even fewer that purchase significant volume. This does provide these buyers with power.

As stated previously, product differentiation in the industry is relatively low and buyers are increasingly viewing large jet engines to be interchangeable. The end user of the airplane has the option of choosing a P&W engine or a competitor's engine, with little to no penalty, provided more than one company has designed an engine for that type of airplane. As most airplanes have multiple engine options, the buyer does have a certain amount of power in selection.

The engine constitutes a large contribution to the quality and service of the buyer's products. This diminishes buyer power to some extent; however, the lack of differentiation between products limits this effect.

Margins in the aerospace industry in general tend to be small. The end users have narrow margins and are thus extremely price sensitive when buying aircraft. Because of this, the aircraft manufacturers are also very price sensitive when purchasing engines. The narrow margins inherent in the aerospace industry increase buyer power and contribute to making this a loss-leader industry. The ability to save the end user money is one aspect where jet engine manufacturers could gain a competitive

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[9] Porter, Michael E. "How Competitive Forces Shape Strategy." Harvard Business Review 57.2 (1979): 137-145. 21 Jan. 2008 http://web.ebscohost.com.libproxy.mit.edu/ehost/pdf?vid=5&hid=107&sid=ba6e32c0-71fd-4dbc-bab3-1d1a24b6b66b%40sessionmgr102.

advantage. End users are anxious to increase margins, and engines with greater fuel efficiency or lower maintenance costs would save end users money. This is one area that companies in this industry are trying to differentiate the product and reduce the bargaining power of buyers.

Once an engine has been chosen and placed into an airplane, the switching cost is high, and that engine is likely to remain in that aircraft. The power for buyers purchasing critical aftermarket parts is therefore low, enabling companies to charge more for aftermarket parts.

There is little threat of buyers integrating backward. It would not make business sense for the end users. As for the airplane manufacturers, jet engines are not their core competency. End users currently like the option of selecting an engine, and backwards integration of the airplane manufacturers would limit this ability. For the same reasons, there is little industry threat of forward integration. There are also monopoly issues associated with integration in this industry, as evidenced by the government's anti-trust ruling in 1934 that split the United Aircraft and Transport Company into three separate entities: United Air Lines, Boeing Airplane Company, and United Aircraft Company, which later became UTC.[10]

The threat level from the bargaining power of buyers is moderate. There are few buyers that generally place large orders, product differentiation is low, products constitute a large percentage of a buyer's costs, and margins are high. The engine is a key element of quality and performance in the buyer's final product. A company that is able to successfully differentiate its product such that it saves the client money would be able to significantly reduce the bargaining power of the buyers. Another way that engine manufacturers try with varying success to limit buyer power is through branding and relationships.

2.1.5. Competitors

The positioning of competitors impacts the industry by setting the level of rivalry. Competitors can upset the balance of positioning through price competition, product introduction, and advertising. The threat from competitors is increased when competitors are roughly equal in size and power, the industry has slow growth, products lack differentiation and switching costs, there are high fixed costs, and when there are high exit barriers.[11] The threat level from competitors in this industry is high.

The competitors within this industry are relatively equal in size and power. The three primary competitors in the industry (UTC, General Electric, and Rolls Royce), are all diversified companies with deep pockets and considerable power. This provides these companies with the necessary cash flow to be

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[10] "History: the Boeing Logbook: 1933 - 1938." Boeing. 2008. 21 Jan. 2008 <http://www.boeing.com/history/chronology/chron04.html>.

[11] Porter, Michael E. "How Competitive Forces Shape Strategy." Harvard Business Review 57.2 (1979): 137-145. 21 Jan. 2008 http://web.ebscohost.com.libproxy.mit.edu/ehost/pdf?vid=5&hid=107&sid=ba6e32c0-71fd-4dbc-bab3-1d1a24b6b66b%40sessionmgr102.

able to withstand the high development costs and fluctuations in the airline industry. This also makes it unlikely that any one of the competitors could be priced out of the industry.

Several additional factors lead to fierce competition between these players. The airplane industry is highly cyclical and volatile, meaning that companies need a large installed engine base to provide profits during upswings to make up for losses on industry downturns. There is limited product differentiation. Historically the players in the industry tried to compete primarily on quality and engine features. However, the gap between engine quality and features among competitors has decreased, making product differentiation on the basis of quality much more difficult. Switching costs for end buyers include the cost of current parts inventory for one engine type if a new engine is selected and training of mechanics to work on a new engine. There are competing engines available for most aircraft. Often the end buyer can select the engine as a feature to be put on the aircraft.

There are high fixed costs in the industry that also feed industry rivalry. Due to the loss-leader business model, once a company has spent the development costs for an engine, these costs need to be recouped through engine sales. Each company typically develops an engine for each type of commercial airplane. The company that dominates engine sales for that airplane will likely make a profit, while the competing company might not make back their development costs. Some end buyers (notably the United States Department of Defense) will pay all or part of development costs for an engine that is preselected for an aircraft. These funds make the business model for engine development much more attractive, especially since the competing company would have to fully fund development for a competitive engine.

There are barriers to exiting this industry. Replacement parts for engines already in service are needed, and currently some critical parts are only available from the original engine manufacturer. Several co-funded development programs are in process and long-term contracts have been established. It is unlikely that the governments and other parties associated with these contracts and the need for repairs would readily allow any one of these companies to exit the market.

Competition between the three players in this industry is intense. The competitors are similar in size and power, the industry is highly cyclical, and there is little perceived product differentiation or switching costs, high fixed costs, and high exit barriers. Branding can be one method of reducing rivalry, but the effect of branding has been decreasing as engines are becoming more commoditized. The threat from competitive positioning in this industry is high.

Since the threat from competitors is high, companies in this industry should focus on addressing this threat. There is nothing a company can do to affect the size or power of its competitors, the cyclical nature of the industry, or the exit barriers. The possible areas where a company can have an impact are on product differentiation and switching costs. Products could be differentiated by quality and technology. These differentiating factors have the highest benefits and greatest likelihood of success when they

achieve a low-cost position or save the buyer money on aftermarket costs such as fuel and maintenance. This is where a company should focus its strategies to decrease the competitive threat.

2.1.6. Summary

Based on Porter's five forces industry analysis, the jet engine manufacturing industry is moderately attractive. The largest threats to incumbents in the industry are suppliers and competitors. Due to the specialization of parts required, some key suppliers have a large amount of power over the manufacturers. Competition is fierce due to the high development costs and difficulty in differentiating products. Buyers present a somewhat lesser threat to incumbents, but do have bargaining power due to low product differentiation, low buyer margins, and the ability to select the engine for each aircraft. New entrants and substitutes present a minimal threat. The high capital requirements and long payback periods make it difficult for a new entrant to successfully enter the industry. There are no close substitutes to a large jet engine. Although there are significant threats in this industry, these threats can be and are being managed and profits are still being made. This is unlikely to change in the near future, making this a moderately attractive industry.

A company has three strategy options in order to deal with and grow in spite of existing threats. These options are to cope with existing conditions and position the company accordingly, to influence the existing force conditions to improve the company's position, or to foresee and take advantage of changing force conditions.[12] By creating a strategy based on one or more of these three options, companies in this industry can manage existing threats to maintain profitability and growth.

2.2. United Technologies Corporation and Pratt & Whitney

Two aspects of UTC that affect procurement costs are the synergies between division supply chains and the efforts of the procurement organization. This section will provide a brief overview of UTC and P&W and discuss how these two aspects affect procurement costs and associated cost-reduction efforts.

2.2.1. Division Synergies

UTC is a $47.8 billion dollar corporation consisting of eight primary business units: Carrier, Hamilton Sundstrand, Otis, P&W, Sikorsky, UTC Fire & Security, UTC Power, and United Technologies

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[12] Porter, Michael E. "How Competitive Forces Shape Strategy." Harvard Business Review 57.2 (1979): 137-145. 21 Jan. 2008 http://web.ebscohost.com.libproxy.mit.edu/ehost/pdf?vid=5&hid=107&sid=ba6e32c0-71fd-4dbc-bab3-1d1a24b6b66b%40sessionmgr102.

Research Center.[13] The corporation is diversified into multiple business areas through its divisions. Three of these divisions (Hamilton Sundstrand, P&W, and Sikorsky) operate within the aerospace industry and share supply chain synergies that can be and are exploited in order to reduce costs.

UTC spends $16.4 billion annually on direct and indirect materials, goods, and services. This means that 34% of the corporation's revenue is tied up in procurement costs each year. $10.4 billion of that cost is for direct materials, and 40% of this amount is spent by the 3 aerospace divisions (Hamilton Sundstrand, Sikorsky, and P&W).[14]

UTC has systems in place to take advantage of the synergies between the aerospace divisions to reduce corporate-wide procurement costs. Each of the UTC divisions operates autonomously and has its own vice president of supply management. The vice presidents of supply management at each of the divisions form a council that meets 11 times a year to collaborate on supply management strategy, policy, and procedure and to share best practices and discuss procurement opportunities.[15]

The three aerospace divisions also coordinate cooperative supply chain efforts through the UTC aerospace supply management team, which was created for this purpose. The team's goals are to align the procurement strategies of the three aerospace divisions, leverage the combined part volume of the divisions to obtain lower pricing, and to act as a knowledge repository and sharing vehicle among the divisions. Collaborative efforts such as these have resulted in approximately $250 million of savings for UTC in recent years.[16]

2.2.2. Procurement Organization

The procurement organizations of UTC and P&W directly affect procurement costs and supply chain establishment and development. As stated above, UTC lets each division manage its own supply chain strategy. The corporation-wide procurement strategy focuses on divisional synergies and high-level goals, with the individual divisions being given latitude to determine how to meet those goals.

P&W is the second largest business unit within UTC, with $11.1 billion in annual revenue in 2006.[17] P&W designs, manufactures, and services aircraft engines, industrial gas turbines, and space propulsion systems. The procurement organization at P&W is designed to present a consistent front to suppliers and to leverage the division's full purchasing volume.

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[13] United Technologies Corporation 2006 Annual Report, Growing From Within, pp. 6 – 7 http://www.utc.com/annual_reports/2006/2006_utc_annual_report.pdf.
[14] Avery, Susan. "Supply Management is Core of Success at UTC." Purchasing 07 Sep 2006: 36 – 38.
[15] Avery, Susan. "Supply Management is Core of Success at UTC." Purchasing 07 Sep 2006: 36 – 38.
[16] Teague, Paul E. "Cross-Divisional Teamwork Nets Big Savings." Purchasing 07 Sep 2006: 45 – 46.
[17] United Technologies Corporation 2006 Annual Report, Growing From Within, pp. 6 – 7 http://www.utc.com/annual_reports/2006/2006_utc_annual_report.pdf.

The procurement organization at P&W consists of a centralized procurement team. This organization was selected to enable control and consistency in procurement activities. By centralizing procurement strategy, negotiations, and supplier management, P&W was able to consolidate work on similar part types within a smaller number of suppliers. This enabled the company to negotiate lower pricing through larger purchasing volumes.

The centralized procurement group is further organized by the various part types, or "commodities", e.g., castings or fabrications. Each of these commodity management groups is responsible for working with suppliers, the P&W manufacturing and assembly facilities, P&W's strategy department, and the other commodity management groups to develop and implement overall strategy with regards to its specific commodity.

The procurement organization at P&W is designed to concentrate purchasing decisions into one group. This provides a single focal point for suppliers and assigns direct responsibility for procurement cost-reduction efforts. One drawback of this system is that procurement managers are responsible for a wide variety of parts for various engine programs and clients, and the managers may not have an in-depth understanding of all of the parts under their control.

2.3. Literature Review

Existing publications on controlling manufacturing and supply chain costs within the jet engine manufacturing industry tend to focus in one of two areas: first, on whether or not companies should outsource work or perform it in-house, and second, on how to develop a supply chain strategy that will facilitate cost reductions. This section will discuss current literature findings on the topic of sourcing in the jet engine manufacturing industry and how this thesis fits within that research.

The first area that existing publications focus on is whether or not a company should outsource work or perform it in-house. Existing literature takes both sides of the argument, with some research supporting global outsourcing and some opposed. Global outsourcing has become more prevalent and companies are being encouraged to outsource themselves or risk being left behind. Companies are being told to identify and focus on core competencies and outsource remaining work wherever the best gains can be achieved.[18] Global outsourcing is being positioned in this research not necessarily as a way to gain competitive advantage anymore, but as a necessary activity to not be outstripped by competitors. Other

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[18] Friedman, Thomas L. The World is Flat: a Brief History of the Twenty-First Century. 2nd ed. New York: Farrar, Straus, and Giroux, 2006.

research contradicts this claim. This research suggests that no performance gains can be seen as a direct result of outsourcing.[19]

Many publications discuss the fact that determining whether or not to outsource work, selecting suppliers for this work, and managing this supply chain are core capabilities that companies need to develop that can be the source of competitive advantage.[20,21] Global outsourcing introduces various risks and hidden costs that are often overlooked in making sourcing decisions.[22] The decision of whether or not to outsource should consider product architecture,[23] balance lower production costs internationally with lower transaction costs locally,[24] and understand all hidden costs involved.[25] One of the hidden costs associated with global outsourcing is the knowledge and technology transfer that occurs to supplier countries. Europe and North America have held dominance in the aerospace industry for the last 50 or more years.[26] Through the outsourcing of design and manufacturing work much of the scientific, technical, and manufacturing knowledge that has been built up in these areas is being transferred to low-cost countries such as China and Russia.[27,28] This trading of intellectual property is eroding the supremacy of Europe and North America in these markets and creating potential future competitors.[29] The literature on whether or not to outsource varies in its tone and overall message, but the research indicates that this topic is important to procurement managers and critical to effectively designing a supply chain.

The second area that research focuses on is how to design an effective supply chain. Determining whether or not to outsource is one crucial part of designing a supply chain, but not the only factor to be

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[19] Mol, Michael J., Rob J. M. Van Tulder, and Paul R. Beije. "Antecedents and Performance Consequences of International Outsourcing." International Business Review 14 (2005): 599-617.
[20] Mol, Michael J., Rob J. M. Van Tulder, and Paul R. Beije. "Antecedents and Performance Consequences of International Outsourcing." International Business Review 14 (2005): 599-617.
[21] Fine, Charles H. Clockspeed: Winning Industry Control in the Age of Temporary Advantage. New York: Perseus, 1998.
[22] Field, Alan M. "Cheaper by What Measure?" Commonwealth Business Media, Inc. Journal of Commerce (2005): 1-19-1-22.
[23] Fine, Charles H. Clockspeed: Winning Industry Control in the Age of Temporary Advantage. New York: Perseus, 1998.
[24] Mol, Michael J., Rob J. M. Van Tulder, and Paul R. Beije. "Antecedents and Performance Consequences of International Outsourcing." International Business Review 14 (2005): 599-617.
[25] Field, Alan M. "Cheaper by What Measure?" Commonwealth Business Media, Inc. Journal of Commerce (2005): 1-19-1-22.
[26] Pritchard, D, and A Macpherson. "Strategic Destruction of the Western Commercial Aircraft Sector: Implications of Systems Integration and International Risk-Sharing Business Models." The Aeronautical Journal (2007): 327-334.
[27] Pritchard, D, and A Macpherson. "Strategic Destruction of the Western Commercial Aircraft Sector: Implications of Systems Integration and International Risk-Sharing Business Models." The Aeronautical Journal (2007): 327-334.
[28] Friedman, Thomas L. The World is Flat: a Brief History of the Twenty-First Century. 2nd ed. New York: Farrar, Straus, and Giroux, 2006.
[29] Pritchard, D, and A Macpherson. "Strategic Destruction of the Western Commercial Aircraft Sector: Implications of Systems Integration and International Risk-Sharing Business Models." The Aeronautical Journal (2007): 327-334.

considered. The existing literature provides insights as to how to measure the performance of an existing supply chain and how to improve that performance.[30,31] Research in this area stresses the importance of viewing company processes in their entirety rather than any individual aspect. Vertical and virtual integration only works within companies up to a certain level of complexity, after which further integration will have negative returns.[32] At this point the company is forced to begin outsourcing work and therefore to develop and evaluate a supply chain strategy. The literature provides empirical models developed to assist companies in the design, measurement of performance, and revision of a supply chain strategy.

Empirical research evaluates motives that outsourcing companies and Chinese suppliers have for entering into international partnerships. Suppliers enter into international partnerships to obtain technical and managerial knowledge and capabilities, to earn profits, and to export products. The outsourcing companies get into international partnerships to enter emerging markets, meet offset requirements, facilitate international expansion, and to take advantage of low-cost sourcing opportunities. The selection of partners for these collaborations is based more on technical fit with the companies' motives than with managerial fit.[33] These data suggest that companies should develop their supply chain strategies to be consistent with the motives of potential suppliers in order to be effective.

Supply chain development research contains various tools and frameworks to aid in developing a supply chain strategy. Michael Hammer developed a Process and Enterprise Maturity Model to provide companies with a framework for designing company processes.[34] A strategic value assessment model was developed by Fine, et al. to introduce a qualitative aspect of the decision-making process.[35]

Existing literature covers the topics of whether or not a company should outsource and how a company can develop an effective supply chain strategy. This thesis assumes that a company has already made the decision to outsource work and therefore does not deal with the make versus buy decision. This thesis builds on the current work on developing an effective supply chain strategy. Frameworks and tools exist within current research to assist in developing a supply chain strategy. This thesis is focused on

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[30] Rohleder, Ken. Measuring Supply Chain Performance: Protocols for Supply Chain Managers. Rohleder Group, Inc. 2005. 14 Jan. 2008 <http://content.ll-0.com/rainmakers/Measuring_Supply_Chain_Performance1.pdf?i=110405112257>.

[31] Hammer, Michael. "The Process Audit." Harvard Business Review (2007): 111-123.

[32] Bhimani, Alnoor, and Mthuli Ncube. "Virtual Integration Costs and the Limits of Supply Chain Scalability." Journal of Accounting and Public Policy 25 (2006): 390-408.

[33] Dong, Li, and Keith W. Glaister. "Motives and Partner Selection Criteria in International Strategic Alliances: Perspectives of Chinese Firms." International Business Review 15 (2006): 577-600.

[34] Hammer, Michael. "The Process Audit." Harvard Business Review (2007): 111-123.

[35] Fine, Charles H., Roger Vardan, Robert Pethick, and Jamal El-Hout. "Rapid-Response Capability in Value-Chain Design." MIT Sloan Management Review (2002): 69-75.

aiding managers with evaluating cost-reduction activities and sourcing decisions to ensure consistency with the company's supply chain strategy.

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3. Developing a Supply Chain Strategy

All companies need to develop, maintain, and abide by an overall supply chain strategy to govern their sourcing and procurement decisions. Historically supply chains tended to be static, but the pace of change within industry has sped up, and supply chains must be fluid enough to adapt with these changes. Key aspects of this strategy include addressing architectural, sourcing, investment, and alliance decisions.[36] This section will focus on those aspects of designing a supply chain strategy that deal with cost-control activities within the supply chain.

Cost-control activities are an important part of a company's overall supply chain strategy. It is important to set up procurement activities in a way that is consistent with the supply chain strategy and that promotes cost reductions. The metrics that a company selects to manage its supply chain and managers impact results, as do the ways in which a company chooses to manage the entire value stream.

3.1. Metric Evaluation

One factor of a supply chain strategy that has great influence on procurement activities is the set of metrics on which procurement managers are evaluated. These metrics provide incentives to managers to act in ways that will result in good metric scores. Metrics can have unintended incentives. One hypothetical example of this is a manager measured purely on contract costs that selects the lowest-cost supplier even though quality problems at that supplier will cost the company more money than is saved. A well-developed supply chain strategy utilizes metrics that provide incentives that are in line with the company's overall goals. Metrics need to be selected carefully to ensure that they reward desired behaviors. Part of developing a supply chain strategy is to utilize a set of metrics that reward behaviors that are consistent with the company's supply chain strategy and to revise or eliminate metrics that do not.

Purchase price variance is the most commonly used metric in evaluating purchasing performance.[37] This metric measures the difference in the average cost of a part from one period to the next. Purchase price variance is one of the primary metrics that P&W uses to evaluate performance of the commodity management groups, the procurement department, and the division. This section provides an evaluation of how purchase price variance generically influences procurement managers' behaviors in the absence of any other relevant metrics.

It is important to understand exactly what purchase price variance measures and how this influences the procurement process. Purchase price variance is calculated as the average cost of a part in

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[36] Fine, Charles H., Roger Vardan, Robert Pethick, and Jamal El-Hout. "Rapid-Response Capability in Value-Chain Design." MIT Sloan Management Review (2002): 69-75.

[37] Rohleder, Ken. Measuring Supply Chain Performance: Protocols for Supply Chain Managers. Rohleder Group, Inc. 2005. 14 Jan. 2008 <http://content.ll-0.com/rainmakers/Measuring_Supply_Chain_Performance1.pdf?i=110405112257>.

the current period minus the average cost for the same part in the previous year. A weighted average can then be used to provide the purchase price variance for all parts for which a procurement manager is responsible. A negative purchase price variance indicates a reduction in costs from the previous period and is the desired result.

The goal for procurement managers is to reduce purchase price variance. Factors such as inflation and rising supplier costs cause increases in purchase price variance. Procurement managers use cost-reduction activities such as lean implementation and supplier negotiations to counter this and decrease purchase price variance.

3.1.1. Benefits

Purchase price variance can be a useful metric for tracking costs and identifying areas for cost-reduction activities. This section discusses the benefits of using purchase price variance as an evaluation metric and how this metric fits within the company's cost-reduction goals.

Purchase price variance looks at one aspect of a supply manager's responsibility: part cost. The primary incentives produced by this metric are to reduce material costs and to reduce value-added costs.

The first primary incentive of purchase price variance is to reduce material costs. In castings and forgings the primary material inputs are metal alloys. Some cost reduction in metals may be achieved through negotiation and volume discounts. The amount of material required can be reduced through improved supplier efficiencies and reduced scrap rates. Purchase price variance incents managers to evaluate options such as these to reduce material costs. Lower material costs save the company money, so this incentive aligns with the company goal to reduce costs.

The second of the primary incentives is to reduce value-added costs. Value-added costs are the suppliers' costs to produce a part - this includes all costs from receipt of material up to, but not including, transportation of the finished part. Reduction of these costs would also save the company money, meaning that this incentive also aligns with the company goal to reduce costs.

3.1.2. Limitations

Purchase price variance can be a very useful metric when used correctly; however, this metric does have limitations and should be used with caution. This metric provides an indication of how material and value-added costs of parts purchased change from period to period. It does not provide information regarding how total procurement costs change. This section discusses the incentives that purchase price variance provides and how these incentives can negatively affect procurement manager's actions.

The incentives to reduce material and value-added costs do not take into consideration that other factors might be more important than cost in selecting suppliers and evaluating procurement managers.

Factors such as quality, speed, service, and flexibility can all be important aspects of a company's supply chain strategy. Purchase price variance does not take these factors into consideration and views additional costs associated with these factors negatively. Companies have complex needs that often require trade-offs between multiple factors, not just costs. Purchase price variance provides an oversimplification that places undue importance on a single factor. This metric can incent managers to select suboptimal suppliers when all factors are considered.

In selecting suppliers based solely on purchase price, the total cost to the company could actually increase. If the selected supplier has poor quality products, the amount of rework, scrap, and the associated costs may increase. If the supplier is farther away than the incumbent supplier, inventory holding costs may increase, and the company's responsiveness may decrease. Surges in demand may result in shortages or missed sales due to the increased shipping time. To counteract this, the company could increase its supply of safety stock or expedite shipping. Both of these would increase costs to the company. The supplier may also require more active supplier management than the incumbent supplier, resulting in higher costs.

Purchase price variance incents cost reduction from period to period. This encourages procurement managers to try to obtain the largest annual price differentials for parts over the years that manager is responsible for those parts. A procurement manager can probably be expected to be in a role for two to three years. This then becomes the timeframe that managers look to reduce costs. This results in short-term contracts with suppliers lasting approximately three years. Longer-term contracts might save the company money in the long run, but the procurement manager has no incentive to do so.

The purchase price variance metric encourages decreasing costs on an individual part or group of parts, without considering how this affects other parts or processes. One example of this is a procurement manager who finds a less expensive casting source in China. However, work on military jet engines cannot be performed within China. The procurement manager therefore moves commercial castings, while leaving military castings at the incumbent supplier. Commercial castings are now cheaper, so the castings procurement manager is rewarded. The original supplier then increases their costs since they now have a smaller volume of work. The total cost to the company may be increased, but the procurement manager in charge of castings is still rewarded.

Using purchase price variance as a metric focuses cost-reduction efforts on the most expensive part categories, which are not necessarily the parts where the greatest savings can be achieved. The most expensive parts are likely to be large, bulky, heavy parts, which would have high shipping and retooling costs and therefore might not be good candidates for resourcing. While there is some success in reducing material costs, for most intents and purposes these costs are assumed to be fixed between suppliers. Cost-reduction efforts therefore only affect the value-added portion of the cost of the purchased part. Parts

with high value-added costs are therefore generally better targets for cost reduction, regardless of the total cost.

Purchase price variance in most companies is dependent upon part numbers and often is not remapped when a part number changes. When a design change is made to reduce manufacturing costs for a part, resulting in a part number change, purchase price variance will not compare pricing for the two part numbers. Any cost savings achieved by the design change will not register.[38] If this occurs, the procurement manager has no incentive to recommend or assist efforts to reduce procurement costs through design changes.

Purchase price variance does not take into account the spread of cost for a given part. One part could be $50 per piece from one supplier and $100 per piece from another supplier. If the low-cost supplier is maxed out on capacity, any increase in demand will result in an increase in purchase price variance. The procurement manager is then penalized based on something outside his or her control.

3.1.3. Summary

There are numerous side effects of using purchase price variance that may not be intended or desired by the company. This metric promotes short-term, discrete cost reductions without considering long-term and company-wide implications. Purchase price variance targets cost-reduction efforts towards parts with the highest increase in purchase price without considering actual savings potential. The usage of this metric can cause procurement managers to be rewarded or penalized for actions outside their control.

Purchase price variance is an important metric, but should be used with caution and in conjunction with additional metrics to incent desired behaviors. The usage of this metric encourages the reduction of material and value-added costs, which benefits the company. However, this metric also provides additional incentives that are often counter to what the company is trying to achieve. The company should be aware of this and implement the usage of additional metrics to align the incentives of the procurement managers with the goals of the company's supply chain strategy.

3.2. Value Stream Management

Value stream management is an important aspect to consider in developing a supply chain strategy. Value stream management is a lean concept that encompasses the management of all of the processes required to make a complete part, from raw material to finished product. Connections between

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[38] Rohleder, Ken. Measuring Supply Chain Performance: Protocols for Supply Chain Managers. Rohleder Group, Inc. 2005. 14 Jan. 2008 <http://content.ll-0.com/rainmakers/Measuring_Supply_Chain_Performance1.pdf?i=110405112257>.

processes should be deliberately designed, not a consequence of sourcing decisions. The design of a product's value stream affects final product costs through not only purchase price, but also by including costs such as shipping and rework. By managing the entire value stream, those expenses that do not add value to the finished product can be minimized. This reduces the cost of the final product and increases the value proposition for all parties in the supply chain. The design of a product's value stream also affects other aspects of a company's business, such as responsiveness. A well planned value chain can be a significant competitive advantage for a company.

3.2.1. Total Landed Cost

The total landed cost of a product is the entire cost to the company to make and/or procure that product. This includes all shipping and rework costs, as well as supplier management and inventory holding costs. One of the purposes of value stream mapping is to be able to identify all of the relevant costs in order to be able to determine the total landed cost. Once the total landed cost has been determined in all areas, it can be used to design a supply chain strategy that minimizes this cost.

Considering total landed cost as opposed to only purchase cost is important to develop a consistent supply chain strategy that manages the entire value stream. As discussed previously, purchase price variance does not take into consideration all of the costs incurred in producing a product. As companies evaluate resourcing options, especially in low-cost areas, evaluating total landed cost as opposed to purchase price is important. Transitioning work to low-cost areas involves costs that do not factor in to purchase price variance. Infrastructure in low-cost areas is often undeveloped, which can lead to costs associated with shipping delays and damaged goods. Countries in low-cost areas may have political or economic instabilities which can affect risks.[39] Suppliers within these countries are often not familiar with western business practices and may be less likely to meet budget, quality, and schedule requirements. Additional hidden costs include taxes, duties, costs associated with carrying additional inventory, and rework costs.

A total landed cost model that includes all costs associated with the selection of suppliers can be a useful tool in value stream management. This model can be used in conjunction with purchase price variance to provide a more thorough view of the costs associated with supplier selection. Jason Kary created a total landed cost model for UTC as part of his 2006 Leaders for Manufacturing thesis at the Massachusetts Institute of Technology. The cost factors Kary considered for inclusion into the model are broken into recurring costs and nonrecurring costs. Recurring costs include: purchase price, ordering cost, inventory holding cost, non-performance cost, transportation cost, on-going coordination cost, and

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[39] Field, Alan M. "Cheaper by What Measure?" Commonwealth Business Media, Inc. Journal of Commerce (2005): 1-19-1-22.

tax cost. Nonrecurring costs include: tooling, equipment, engineering qualification, relocation expenses, insurance, contract termination costs, and other set-up costs. Kary's thesis provides an in-depth look into cost models and their potential usage at UTC. The thesis concludes that total cost models can provide valuable insights into the total costs of procurement, but cautions that these models consider only costs and that strategic reasoning should also be considered in making sourcing decisions.[40]

Total landed cost can be used to supplement purchase price variance in managing a value stream. This provides a more complete view of procurement costs than purchase price variance alone. Total landed cost is limited in that it provides a view of only cost considerations and does not take into account strategic considerations. Both should be taken into account in developing a supply chain strategy.

3.2.2. Materials Control Laboratory

All of the processes involved in procuring a part should be considered in managing the value stream. Quality and conformance inspections performed at materials control laboratories are crucial processes in the aerospace industry. Due to the highly sensitive nature of the product, rigorous testing procedures are required by the Federal Aviation Administration and by P&W. All laboratories that perform this testing must be approved to do so. In developing a supply chain strategy in the jet engine manufacturing industry, a materials control laboratory is an important aspect to consider.

A supply chain strategy that involves resourcing work should address where quality and conformance inspections will be performed during and after the work is transitioned. Most current suppliers have approved materials control laboratories, and P&W does verification testing as required and appropriate. New suppliers without approved materials control laboratories would need to develop the necessary capabilities and gain approval, or outsource testing to an approved laboratory. Developing the necessary capabilities would take time and be expensive. Outsourcing testing would require additional shipping of the parts, resulting in higher shipping costs. Shipping the parts to a laboratory is a non-value-added cost and presents an additional step where damage to the parts could occur. Some rework after testing is allowed in order to get parts within specifications. If testing is not done in-house, additional shipping would be required to return parts to the suppliers for rework, and then to ship it back to the laboratory, introducing additional costs and damage opportunities. The approved laboratory would likely be either P&W or one of the company's current suppliers. Current suppliers would likely charge a premium to test work that had been taken away from them, making this an unattractive option. Testing is not P&W's core competency, and to take this on as a company would be a disruption, making this option also unattractive.

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[40] Kary, Jason R. Advanced Aerospace Procurement Models with Sensitivity Analysis and Optimized Demand Allocation. MIT Leaders for Manufacturing Program. Cambridge: Massachusetts Institute of Technology, 2006.

Testing at a materials control laboratory is one aspect of the supply chain that should be taken into consideration when developing a supply chain strategy and making sourcing decisions in this industry. The ideal situation is for the supplier to provide testing. If this is not possible, then a laboratory nearby is the next best solution to reduce shipping costs and potential damage opportunities.

3.2.3. Summary

Consideration of total landed costs and materials control laboratories will assist procurement managers in managing a product's value stream. A supply chain strategy needs to consider factors such as these and set up incentives for procurement managers accordingly. Procurement managers should be able to view and track costs throughout a product's value stream, and should be incented to reduce costs while maintaining consistency with the supply chain strategy. Depending on the product and its current and proposed supply chain, there could be numerous other factors to consider in managing the value stream. The procurement managers should trace the value stream from material to finished product to determine what those factors are and how to best optimize them.

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4. Evaluating Cost-Reduction Alternatives

In developing a procurement strategy, companies should evaluate a variety of cost-reduction techniques and the ways in which these techniques complement and contrast each other. A successful procurement strategy should include multiple cost-reduction techniques working together to reduce costs. Some possible methods of reducing costs include:

- Increasing supplier efficiencies;
- Designing less expensive parts;
- Negotiating lower supplier margins; and
- Sourcing in low-cost areas.

This list is not intended to be exhaustive. These options were selected because they are applicable to castings and forgings in the jet engine manufacturing industry and present a variety of the available alternatives. Any company developing a procurement strategy should tailor this list to their business, industry, and supply chain strategy. This can be done by identifying costs throughout the supply chain through the use of total landed cost models and value stream management, and then identifying possible methods for reducing those costs.

This section will provide a brief evaluation of each of these cost-reduction alternatives as they relate to the jet engine manufacturing industry and P&W specifically. The performance criteria that will be considered for each alternative are:

- Cost-reduction potential;
- Investment required;
- Simplicity;
- Risk level;
- Ease of implementation; and
- Timeline.

The alternatives will be evaluated based on each of the six performance criteria and rated from one to five, with five indicating the best performance and one indicating the worst. The basis for the rankings of the performance criteria are provided in Table 2. These rankings are generalized estimates based on the experience of working at P&W and are intended to provide relative, not actual, performance approximations.

	Performance Criteria					
Rank	**Cost-Reduction Potential**	**Investment Required**	**Simplicity**	**Risk Level**	**Ease of Implementation**	**Timeline**
1	Negligible	Extensive	Extensive Internal & External Coordination	Extensive	Prohibitive Barriers	Years
2	Minor	Considerable	Some Internal & External Coordination	Considerable	Strong Barriers	Quarters
3	Moderate	Moderate	Some External Coordination	Moderate	Moderate Barriers	Months
4	Considerable	Minor	Some Internal Coordination	Minor	Weak Barriers	Weeks
5	Extensive	Negligible	Negligible Coordination	Negligible	Negligible Barriers	Days

Table 2: Basis for Performance Criteria Rankings

The performance criteria are evaluated from the engine manufacturer's point of view, not the supplier's. For example, cost-reduction potential considers the reduction in costs to the engine manufacturer, but does not consider any additional costs to the supplier. The cost-reduction potential refers to the total amount of money that could potentially be saved by the engine manufacturer by this alternative. This is imperative to determining if an option is worth pursuing. The investment required criterion considers the amount of money required to obtain these cost reductions. Simplicity refers to the amount of resources and organization required to implement the alternative. For example, can the alternative be implemented within one department, or will it require coordination among various departments and companies? Risk level identifies and evaluates potential threats that may arise as a result of the alternative being implemented. Ease of implementation evaluates barriers to implementation. Barriers could range from legal concerns to cultural hindrances to political factors. The timeline criterion ranks alternatives based on how long it will take to recognize the savings attained. The rankings for the alternatives evaluated in this section are summarized in Table 3. These rankings are discussed in detail within this section. These rankings are subject to change with time and industry variability. The relative importance of the factors is company-specific and depends on what a company is trying to achieve with its supply chain strategy.

The importance of the six categories will change depending on the situation. The challenges presented by one performance criterion might preclude the benefits. For example, an alternative that scores highly in all of the six categories except cost-reduction potential and ease of implementation may still be unattractive since a lot of effort would be required for little gain.

	Alternatives			
	Increase Supplier Efficiencies	**Design Less Expensive Parts**	**Negotiate Lower Supplier Margins**	**Source in Low-Cost Areas**
Cost-Reduction Potential	5	5	2	4
Investment Required	3	4	4	1 - 5
Simplicity	3	1	3	1
Risk Level	4	3	4	1 - 4
Ease of Implementation	2 - 3	3	2 – 3	2
Timeline	1 - 5	1	1	1 - 3

Table 3: Cost-Reduction Alternatives Evaluation Rankings (5: best; 1: worst)

An in-depth evaluation of low-cost sourcing alternatives is provided in Section 5. The evaluation of cost-reduction alternatives in this section is intended to provide an overview of a wider array of alternatives that should be considered in addition to and as complements of any low-cost sourcing initiative. This evaluation is intended as a preliminary screening and indicator of the viability of these alternatives. It is not intended to constitute a thorough evaluation. Companies should use this preliminary screening to identify viable alternatives that are worth further consideration, and then conduct a more thorough evaluation of these alternatives using a framework similar to the one developed to evaluate low-cost sourcing alternatives in Section 5. In particular, companies must consider how each alternative fits within the company's supply chain strategy. No alternative should be implemented in a vacuum.

4.1. Increase Supplier Efficiency

This alternative involves implementing methods such as six sigma and lean manufacturing within a supplier's facility in order to reduce procurement costs. Lean manufacturing has become a staple of cost-reduction efforts for many manufacturing companies. In essence, lean manufacturing is a continuous process of eliminating all unnecessary waste in order to improve process efficiency and reduce costs. Lean manufacturing can be used within a company but is most effective when utilized throughout the entire supply chain. By assisting suppliers to implement lean manufacturing, the suppliers' costs can be reduced, thus lowering product costs and increasing value for the suppliers and the purchaser. This section will evaluate this alternative with regard to the six performance criteria.

4.1.1. Cost-Reduction Potential

There are inefficiencies within any manufacturing process, making the cost-reduction potential of this alternative highly attractive. Up to 70% or more of manufacturing costs are generally non-value-

added.[41] This presents a lot of opportunity for lean activities to reduce costs at current suppliers by eliminating non-essential waste. The potential for savings will vary by supplier and by process, but overall cost-reduction potential is likely to be extensive. The ranking for this criterion is five.

4.1.2. Investment Required

It is not anticipated that the investment required from the engine manufacturer would be substantial. There are investment costs associated with convincing a supplier to implement lean practices and with demonstrating to suppliers how to do so. Suppliers will generally carry a large percentage of the investment costs for improving their own efficiencies. Some smaller suppliers may not have enough capital to fund their own lean activities, so some investment may be necessary. The investment required for this alternative is moderate and has a ranking of three.

4.1.3. Simplicity

This alternative is relatively simple from the company's perspective, although it can be quite complex from the supplier's perspective. In most cases, only a small team from the engine manufacturer would be required to work with the supplier to demonstrate lean practices and the potential benefits. The level of involvement of the supplier will often require high level management approval within the supplier and dedication from a core group of employees. Smiths Aerospace provides an example of an aerospace supplier that has implemented lean initiatives to reduce costs. Some of the activities Smiths has implemented include using value stream mapping, reducing duplicated efforts, revising the organizational structure, and improving review processes.[42] Some of these activities are highly involved. Although this alternative is complex from the supplier's perspective, this alternative is reasonably simple from the company's perspective, requiring only minimal internal and external coordination, and ranks a three.

4.1.4. Risk

Risks to the engine manufacturer as a result of this alternative include sacrificing product quality and consistency and damaging supplier relationships. In general, six sigma and lean manufacturing

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[41] Astall, Chris. "Offshore Manufacturing [Lean Manufacturing as an Alternative]." Engineering Management Journal 6 (2005): 37. 16 Jan. 2008 <http://ieeexplore.ieee.org.libproxy.mit.edu/search/searchresult.jsp?coll1=ieeejrns&coll4=ieejrns&history=yes&reqloc=others&queryText=%28lean+%3Cin%3E+metadata%29+%3Cand%3E+%282221+%3Cin%3E+punumber%29&scope=metadata&imageField2.x=13&imageField2.y=2>.

[42] Waters, Mike, and Jon Bevan. "Journey to Lean [Lean Practices in Aerospace Product Development]." Engineering Management Journal 15.4 (2005): 10-13. 16 Jan. 2008 <http://ieeexplore.ieee.org.libproxy.mit.edu/iel5/2221/32304/01507606.pdf?tp=&arnumber=1507606&isnumber=32304>.

techniques are designed and implemented to reduce process and part variability and improve quality. However, there are risks inherent in changing over current processes, and especially during transition phases, part quality could suffer. These risks can be mitigated by putting a transition plan in place and tracking part quality and consistency throughout the transition to catch any problems early on. The other risk with this alternative is that the supplier relationship could be damaged. Suppliers may resent other companies telling them how to perform their work and may take this as a slight to their capabilities. This can be mitigated by being open with suppliers and by leveraging examples where the engine manufacturer has utilized some of these techniques to its benefit. There are some risks with this alternative, but they are slight and can be mitigated. The risk level for this alternative has a ranking of four.

4.1.5. Ease of Implementation

The ease of implementing this alternative varies greatly depending on the supplier. With an eager supplier willing to do the majority of the work itself, this alternative can be implemented relatively easily and with minimal resources required from the company. A supplier that is not eager to work together to achieve manufacturing cost reductions represents a huge barrier to implementing this alternative. As discussed in the previous section, lean activities can be highly involved and complex. Management approval and participation is vital to the success of any lean implementation. Therefore suppliers must be motivated to participate in improving their efficiencies and willing to share the benefits with the company. As discussed in Porter's five forces analysis in Section 2.1.2, some of the suppliers have considerable power over the companies in this industry. This makes it difficult for the companies to convince the suppliers to participate in initiatives such as this. For suppliers with less supplier power, this is not as large of an issue. Barriers for this alternative are moderate to strong, depending on the supplier power of the supplier in question and the supplier's willingness to cooperate. The ranking for ease of implementation for this alternative ranges from two to three.

4.1.6. Timeline

The timeline for implementing lean manufacturing varies depending on the activity and on the company. Some inefficiencies could be easily removed and produce immediate results, while other practices could take years or decades to achieve savings. This alternative is given a ranking ranging from one to five.

4.1.7. Summary

Improving supplier efficiencies is a valid way to achieve cost reductions, yet it relies heavily on how motivated the supplier is. There are large potential cost savings. The role of the company is primarily to act in an advisory role, but can also involve becoming involved in change management

within the supplier. Investment is generally the responsibility of the suppliers, but can be shared by the engine manufacturers. The main barrier to implementation is the high bargaining power of some suppliers, which makes it difficult to motivate suppliers to invest the necessary resources into improving their processes. The timeline for these improvements varies greatly depending on the complexity of the changes being implemented.

4.2. Design Less Expensive Parts

While lean manufacturing is well-documented and established within the aerospace industry, lean engineering is a less-utilized method of reducing costs. Lean engineering refers to using continuous improvements to eliminate waste in engineering processes and designing for manufacturability. The three key elements of lean engineering are to create the right product, with effective lifecycle and enterprise integration, using efficient engineering processes.[43] Creating the right product with effective lifecycle and enterprise integration helps to reduce manufacturing and redesign costs. Using efficient engineering processes would help to reduce design costs, but as the focus of this thesis is on reducing procurement costs, this section will focus on the first two elements of lean engineering.

Lean engineering is most effective when it is implemented within the initial design phases of an engine and when suppliers are included in the design phase. Design changes could be made to existing parts; however, this would not be as effective and is thus a less attractive alternative. Changing the design of existing parts would result in less cost-reduction potential since the future estimated part volume would be smaller, and engineers would likely be more hesitant to make large changes. Greater investment would be necessary to cover costs for redesign, engine tests if necessary, and getting a supplier up to speed on the revised part. This would be much more complex in requiring input from current suppliers and internal and external customers, and would encounter a lot more resistance. The timeline for these changes could still be lengthy due to the time required for the redesign, testing, approval, and ramp-up of revised parts. This section focuses on the more attractive alternative of implementing lean engineering in the initial design phases of an engine program.

4.2.1. Cost-Reduction Potential

The cost-reduction potential of this alternative is extensive since manufacturing costs are largely dictated by the design of the part. The design process determines approximately 80% of a product's

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[43] McManus, H L., A Haggerty, and E Murman. "Lean Engineering: a Framework for Doing the Right Thing Right." The Aeronautical Journal 111.1116 (2007): 105-114. 16 Jan. 2008 <http://www.raes.org.uk.libproxy.mit.edu/pdfs/3042.pdf>.

lifecycle costs.[44] A product's design determines the materials the part is made up of, the manufacturing process to be used, and the inspections required. Once the design is complete, it becomes much more difficult to make changes in these areas to reduce costs. Thus there is plenty of opportunity to reduce a product's costs in the design phase. This criterion is ranked five.

4.2.2. Investment Required

Revising the design process to include design for manufacturability and to consider costs does not constitute a major investment for the company. The investment required might include some training of design engineers and perhaps some organizational changes, but primarily this alternative represents a shift in the way things are done, not the addition of new work. The investment required is minor, and this criterion is ranked four.

4.2.3. Simplicity

The simplicity of designing less expensive parts is affected by the design specifications of the parts. Designing a jet engine requires a number of trade-offs among various factors. Some of the factors an engineer has to consider in designing an engine include performance, safety, weight, noise, pollution, and cost. These trade-offs are especially evident when considering castings. This section will look at some of the trade-offs involved in designing castings for a jet engine and evaluate the option of designing less expensive parts to reduce costs.

Not all design criteria carry the same amount of importance. The Federal Aviation Administration regulates some factors, such as safety, and P&W has their own specifications for these criteria as well. Obviously, safety comes before factors such as cost; however, at some point the engine is determined to be safe enough, and cost needs to be factored in. This is why trade-offs are such a necessary part of designing an engine.

Even within castings, design criteria differ depending on the engine part. Certain parts have more stringent specifications due to their operating criteria. Airfoils are vital parts within an engine and need to operate at extremely high temperatures. Failure of an airfoil could cause costly damage downstream within the engine. The primary design criteria for airfoils are performance characteristics, such as yield, burst, creep, low-cycle fatigue, and crack growth rate. Secondary design criteria likely include manufacturability, cost, high-cycle fatigue, stress corrosion, and fracture toughness. Less critical castings would likely have similar design criteria, though the design specifications would be less stringent.

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[44] McManus, H L., A Haggerty, and E Murman. "Lean Engineering: a Framework for Doing the Right Thing Right." The Aeronautical Journal 111.1116 (2007): 105-114. 16 Jan. 2008 <http://www.raes.org.uk.libproxy.mit.edu/pdfs/3042.pdf>.

Superalloys have become increasingly important in the production of jet engines and the production of castings in particular due to their strength characteristics at high temperatures. There is some discrepancy as to the exact classification of a superalloy, but in general, these are nickel, iron-nickel, and cobalt-based alloys designed to operate at temperatures above approximately 1,000 degrees Fahrenheit (540 degrees Celsius).[45] The production of superalloys is more expensive than that of traditional metals, yet their usage in jet engines has increased from approximately 10% of the total weight of a jet engine in 1950 to approximately 50% by 1985.[46] As materials that have strength at higher temperatures are developed, the performance of the engine improves, but so does the cost of the materials.

There are three primary types of castings produced using superalloys: polycrystalline equiaxed castings, directionally solidified castings, and single-crystal directionally solidified castings. Equiaxed castings have multiple grains of varying sizes. These castings are produced by traditional investment casting processes and have the lowest strength capabilities. The strength of an equiaxed casting part is controlled by the grain boundaries, and creep is the most common failure mode.[47]

Directional solidification was developed for the production of airfoils by Frank VerSnyder and associates at P&W and TRW in the 1960s.[48] These castings are created by attaching a chill plate to one end of the mold and withdrawing the mold at a controlled rate from a heated chamber. This produces parts with multiple grains aligned parallel to the stress axis. Directionally solidified castings have improved strength and life properties over equiaxed parts, but grain boundaries still exist.

The processing mechanism for single-crystal directionally solidified castings procedures was initially discovered by Barry Piearcey at P&W in the 1960s. These castings are produced by the same process as directionally solidified castings, but a helical constriction is used so that instead of parallel grains, a single crystal is preferentially selected and only one crystal is formed.[49] By this means grain boundaries are eliminated, resulting in even greater strength and life characteristics.

As one progresses from equiaxed parts to directionally solidified parts to single-crystal directionally solidified parts, strength and life properties increase. Unfortunately, so do costs. Selecting a casting process and an alloy results in trade-offs between these factors.

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[45] Donachie, Matthew J., and Stephen J. Donachie. Superalloys: a Technical Guide. 2nd ed. Materials Park, OH: ASM International, 2002. 2.
[46] Donachie, Matthew J., and Stephen J. Donachie. Superalloys: a Technical Guide. 2nd ed. Materials Park, OH: ASM International, 2002. 8.
[47] Sharke, Paul. "Lost & Foundry: an Ancient Art Form Exhumed by Modern Engineering Tools Makes Possible Hyperefficient Gas Turbines." Mechanical Engineering 2000. 16 Jan. 2008
[48] Sims, Chester T. "Superalloys: Genesis and Character." Superalloys II. Ed. Chester T. Sims, Norman S. Stoloff, and William C. Hagel. New York: John Wiley & Sons, Inc., 1987. 22.
[49] Sharke, Paul. "Lost & Foundry: an Ancient Art Form Exhumed by Modern Engineering Tools Makes Possible Hyperefficient Gas Turbines." Mechanical Engineering 2000. 16 Jan. 2008 <http://www.memagazine.org/backissues/membersonly/sept00/features/lost/lost.html>.

Designing less expensive parts is a complicated way to reduce overall costs, since performance and safety outweigh cost in terms of design criteria. There is rarely a case where cost can be decreased without affecting one or more other factors. These trade-offs must be carefully considered. Above all, engineers should always keep in mind the customer and end-user requirements and preferences when creating a design. While the majority of the change required by this alternative is within the design engineering group, the option requires making trade-offs that involve almost all parties. This alternative is ranked one for simplicity.

4.2.4. Risk Level

Designing less expensive parts introduces risks associated with making the trade-offs discussed in the previous section and with introducing new or revised parts and processes. Selecting an equiaxed part rather than a single-crystal part may save money in processing costs, yet this may reduce the safety factor involved. The level of risk associated with these revisions varies depending on part criticality and what trade-offs are being made. However, safety factors and other criteria will still be considered, and testing should identify most of the risks associated with these trade-offs. The other area where risk is introduced is through the introduction of new or revised processes. The learning and experience curves present in the industry that were discussed in Porter's five forces analysis in Section 2.1.1 are based on current design and manufacturing processes. Changing these processes that are currently being performed could negate some of the benefits these curves provide. By designing parts for manufacturability, the risks associated with new or revised processes should be minimized. The risk level for this alternative has a ranking of three.

4.2.5. Ease of Implementation

Within the company itself, this alternative primarily represents a shift in the way design engineers perform their jobs. This requires a cultural shift within the company that could represent a barrier to implementation. This alternative also represents a shift in the way suppliers are involved in the design process and potentially results in changes in the supplier's manufacturing processes. This requires a cultural shift within suppliers that could also represent a barrier to implementation.

Engineering design decisions should be made with a full understanding of all of the factors involved. Design engineers are generally tasked with providing certain weight and performance criteria, but rarely do their incentives relate to the cost to manufacture a part. Because of the sensitivity of the product, a highly conservative culture has evolved in the jet engine manufacturing industry, where engineers err on the side of safety. While this is laudable, in some cases the improvement in safety is negligible and results in a large increase in cost.

One aspect design engineers must keep in mind is the manufacturability of a part. In the worst-case scenario, a design engineer may design a part that cannot be consistently produced. More often, a part may be designed that is expensive to manufacture, while a relatively minor design change to that part would have greatly decreased manufacturing costs with negligible performance sacrifices. By the time it is discovered that a part is impossible, difficult, or expensive to make, a lot of money is invested in the design and sourcing of that part. Manufacturability should be considered early in the design process to minimize these occurrences.

Reducing part count is another way to reduce overall costs associated with the engine. Any time a part can be shared between two engine programs, or eliminated entirely, the design costs, tooling costs, ramp-up costs, inventory holding costs, and spare parts costs are all decreased or eliminated, other factors being equal.[50]

By considering manufacturing early in the design process, manufacturing and redesign costs can be minimized. Design engineering managers will want to carefully evaluate this alternative in the design process and in setting up incentives for design engineers. Because incentives and a cultural change are involved, implementation could be more difficult than anticipated. These are considered to be moderate barriers to implementation and this alternative is ranked three for ease of implementation.

4.2.6. Timeline

The timeline for this alternative to produce costs savings is dependent on the development time of the engine. This alternative works best when implemented starting in the initial design phases. Therefore it is most effective in the design of new programs. The timeline from initial design to first sale for an engine can be anywhere from around six to twelve years. Some savings would be seen prior to this in activities such as ramping up suppliers, but the majority of savings would not be seen for years. This alternative is ranked one for timeline.

4.2.7. Summary

Designing less expensive parts is a viable option with the potential for large cost savings. This alternative achieves the best results when implemented during the initial design phases of an engine program. Little investment is required to implement this alternative. The main issues to consider with this alternative are ensuring that design engineers understand and consider cost in their initial design

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[50] McManus, H L., A Haggerty, and E Murman. "Lean Engineering: a Framework for Doing the Right Thing Right." The Aeronautical Journal 111.1116 (2007): 105-114. 16 Jan. 2008 <http://www.raes.org.uk.libproxy.mit.edu/pdfs/3042.pdf>.

while being fully aware of the trade-offs that are being made. The timeline for this alternative can be very long since major results will not be seen until the engine goes into production.

4.3. Negotiate Lower Supplier Margins

One way of achieving cost reduction is by negotiating lower supplier margins. This alternative involves procurement personnel exercising leverage over suppliers to lower pricing on parts supplied to the company. In the absence of suppliers achieving additional cost reductions, this alternative directly takes profits from the supplier and either gives them to the company or passes them on as savings to the buyer.

4.3.1. Cost-Reduction Potential

The cost-reduction potential for this alternative depends on the level of cost currently at each supplier and what that supplier's existing profit margins are. Greater savings can generally be achieved on higher cost parts where a percentage margin results in a larger quantity of money. Margins in the aerospace industry are generally not large, so the cost savings for this option is minor. This criterion is ranked two.

4.3.2. Investment Required

Supplier negotiations generally require minimal investment. Resources required include the time and efforts of negotiation personnel. This criterion is ranked four.

4.3.3. Simplicity

This alternative is relatively simple as it tends to follow regular proceedings within the company. However, supplier negotiations could involve joint cost studies or partnering exercises, requiring coordination between the two companies. Negotiating lower supplier margins is ranked three for simplicity.

4.3.4. Risk Level

This alternative introduces the risk of damaging supplier relationships and the risk that a supplier's margins will be made so low that the supplier becomes unprofitable and goes out of business. The risk of damaging supplier relationships through negotiations can be mitigated by being honest in negotiations. Negotiators should also consider the profitability of the supplier company, which will aid in maintaining supplier relationships while mitigating the risk of a supplier going out of business. Suppliers with high bargaining power will likely protect their own interests, making the risk of putting those particular suppliers out of business negligible. Overall, the risk level for this alternative has a ranking of four.

4.3.5. Ease of Implementation

This alternative is fraught with barriers to implementation. As stated previously, margins within the aerospace industry tend to be small, and suppliers will not be content to accept lower profit margins. This alternative takes no supplier costs out of the equation; it simply shifts profits from the suppliers to the company or passes them through as savings to the buyers. As discussed in the Porter five forces analysis in Section 2.1.2, some suppliers in this industry have high bargaining power, and for those suppliers, this alternative is highly unlikely to succeed. Some suppliers would prefer to lose the business than to decrease their margins. While this option may be easier to implement with suppliers with less supplier power, the relationship between the company and the supplier would likely suffer. Suppliers would not appreciate being forced out of their profits. In the worst case, this could put those suppliers out of business. In the best case, it still strains the relationship, which could make future negotiations and business dealings less fruitful. Suppliers would likely be less willing to share cost and related information with the company, preferring to try to hide their real profit margins. Suppliers would probably be less willing to participate in other cost-reduction efforts such as lean implementation. The strained relationship could result in less responsiveness, willingness to work together, and attention to detail on the part of the supplier. The barriers to implementation range from strong for suppliers with high supplier power to moderate for suppliers with less supplier power. This alternative is ranked two to three for ease of implementation.

4.3.6. Timeline

The timeline for this alternative depends on existing contracts with suppliers. Once lower supplier margins were negotiated into supplier contracts, the cost savings would follow shortly thereafter. Since supplier contracts in the industry tend to be longer than one year, the timeline for negotiated savings to have an effect is ranked one.

4.3.7. Summary

Negotiating smaller supplier margins is a relatively low-risk solution with a low investment cost, but the potential gains are low and likely outweighed by the difficulty with implementation. This option does not create more value in the supply chain, but rather shifts profits from the suppliers to the engine manufacturer or passes the savings on to the buyer. High supplier bargaining power represents a barrier to implementation. This option should be exercised with care towards how suppliers will react and how this will affect the company's relationship with suppliers.

4.4. Source in Low-Cost Areas

As competition in this and other manufacturing markets increases, moving work to low-cost areas has become increasingly popular. This section will provide a general evaluation that encompasses the three options discussed in detail in Section 5:

- Forming low-cost partnerships with current suppliers;
- Finding or creating a domestic low-cost source; and
- Developing, purchasing, or partnering with suppliers in low-cost areas.

4.4.1. Cost-Reduction Potential

Low-cost sourcing has the potential for good cost reductions. Labor and overhead are two major components to value-added costs. These would be reduced in low-cost areas, making this alternative appealing for parts with large value-added costs. There are additional recurring costs involved in making this option viable when work is moved from domestic locations overseas. The costs associated with managing a supplier at an overseas facility are higher due to increased travel costs. Extra inventory holding costs would be likely to maintain the necessary response times and supplier flexibility since shipping times would be increased. Expedited shipping costs would also be higher when necessary, and likely needed more often due to the lengthened response time.

If managed correctly, this option could provide considerable cost reductions. Exact reduction potential should be evaluated on a case-by-case basis. This alternative is ranked four for cost-reduction potential.

4.4.2. Investment Required

The level of initial investment required with this alternative varies depending on the situation. If a supplier has an existing facility in a low-cost area and no additional tooling or ramp-up costs are required, the initial investment could be negligible. If a partnership is created to build a new facility in a low-cost area, the initial investment could be extensive. The amount of investment required from the company depends on the maturity of the supplier in the western aerospace market, the amount of cash flow that the supplier has available, and the terms of any deal between the company and the supplier. Current suppliers would likely require minimal, if any, development costs, while new suppliers could require years of development assistance. Large suppliers with high cash flow would probably carry most of the investment costs, while smaller suppliers may not have the cash to do so. The amount of investment required for this option ranges from negligible to extensive, and the ranking ranges from one to five.

4.4.3. Simplicity

While the simplicity of this alternative varies based on the situation, in most instances this option is fairly complex. At a minimum, coordination between the supplier and the company is required. Most cases will require the involvement of the legal department, the financial department, the engineering department, supplier management, and the strategy department. All players will likely have their own agenda and goals to meet, and aligning those goals could be difficult. If a new supplier is involved, relationships will need to be forged. That supplier will need to be developed to some extent, which may be substantial. For overseas work, a new culture will need to be learned and managed. Extensive internal and external coordination will be required. The simplicity of this alternative is ranked one.

4.4.4. Risk Level

There are numerous risks associated with sourcing work in low-cost areas, specifically when that work is moved overseas. Suppliers in low-cost countries may be unfamiliar with western aerospace requirements, which could lead to decreased quality and increased scrap and rework costs. Flexibility within the supply chain may be reduced due to longer shipping and lead times. Political and economic instabilities may impact the supply chain. Risks for this alternative vary from minor in situations where work is being transferred with a known supplier to an existing facility in a low-cost area, to extensive in situations where a new supplier with a new facility is being developed to perform work that is currently not within that supplier's capabilities.

The risks associated with sourcing in low-cost areas vary greatly from minor to extensive depending on the situation. These risks are discussed in greater detail in Section 5. The ranking of risk level for this alternative ranges from one to four.

4.4.5. Ease of Implementation

There are numerous barriers to implementing low-cost sourcing. One barrier is the difficulty of finding a supplier or facility in a low-cost area that can either do the necessary work or that is capable of being developed to do the work. Another barrier is the difficulty of finding a way to motivate that supplier or facility to do so. Assuming an appropriate facility has been found and convinced to do the work, the next step is to align the goals of the participating groups and develop a plan that benefits all parties, setting up the necessary incentives and safeguards. Then this plan needs to be executed.

Additional barriers to the execution of such a plan include dealing with a foreign culture and customs, being willing to invest the necessary money to develop suppliers as necessary, and addressing difficulties in communications and travel due to distance and time zones. It is more difficult to remain well-informed of a supplier's activities and development when the supplier is further away. Procurement managers and other company employees may resist implementation due to fears or concerns with working

in unfamiliar territory and moving work away from current suppliers. A cultural shift within the company is necessary to embrace this alternative, and represents a barrier to entry.

The barriers to implementation for this alternative are strong, complex, and deep-rooted, involving a cultural change within the company. Ease of implementation has a ranking of two.

4.4.6. Timeline

The timeline for this option depends on the situation. If work is being moved to a supplier's current facility in a low-cost area, results could be achieved in a matter of months. If a new facility is being created from scratch, those results could take years to materialize. With low-cost sourcing there will generally be some amount of supplier development required, which takes time, especially if the supplier is unfamiliar with western aerospace requirements. This alternative ranking ranges from one to three for timeline.

4.4.7. Summary

Low-cost sourcing comprises a number of variables to be considered when deciding if this is a viable method of reducing costs. There exists the potential for large cost reductions in parts with high value-added costs. These gains are somewhat offset by increased logistics and communications costs. Low-cost sourcing can often involve high investment costs and has numerous risks and barriers to entry that must be overcome. Low-cost sourcing will be evaluated in greater detail in Section 5.

4.5. Cost-Reduction Techniques Comparison

Four methods of reducing costs within a company's supply chain were discussed and evaluated herein:

1. Increase supplier efficiency;
2. Design less expensive parts;
3. Negotiate lower supplier margins; and
4. Source in low-cost areas.

These methods were each rated from one to five, with five being the most attractive, with regards to cost-reduction potential, investment required, simplicity, ease of implementation, and timeline. Table 2 provides a summary of the basis for ranking these criteria. Table 3 provides the rankings for each of these alternatives.

The relative standards provided in Table 2 can be assigned values appropriate to a given company and industry to tailor this evaluation. One possible scenario within the jet engine manufacturing industry is provided in Table 4. The cost-reduction potential can be used as either a percentage cost reduction (as it is in Table 4) or a total monetary savings. The amount of investment required can be considered on a

total expenses basis (as in Table 4) or from a rate of return perspective. The simplicity of an alternative can be ranked based on the organizational involvement of supplier and company personnel.

	Performance Criteria					
Rank	**Cost-Reduction Potential**	**Investment Required**	**Simplicity**	**Risk Level**	**Ease of Implementation**	**Timeline**
1	< 2%	> $1M	UTC Corporate & Supplier Corporate Heavily Involved	E	Organizational & Cultural Changes	>10 Yrs
2	2 – 5%	$100K<x<$1M	UTC Corporate & Supplier Corporate Involved	D	Organizational Changes	4Yrs>x>10Yrs
3	5 – 15%	$50K<x<$100K	High-Level P&W & High-Level Supplier Involvement	C	Cultural Changes	1Yr>x>4Yrs
4	15 – 25%	$5K<x<$50K	Procurement Managers & Suppliers Involved	B	Process Changes	6Mos>x>1Yr
5	> 25%	< $5K	Procurement Managers Involved	A	Negligible Barriers	<6 Mos

Table 4: Potential Scenario for Cost-Reduction Evaluation at P&W

Ranking risks can be difficult since many risks, such as workforce skill level and infrastructure, are intangible and difficult to measure. Various ranking systems exist for rating the risk level within a supplier company. Companies such as P&W may have their own information regarding risk level and wish to utilize those rankings. One source of country risk data is the Economist Intelligence Unit, which provides country risk data based on security risk, political stability risk, legal & regulatory risk, tax policy risk, labor market risk, and infrastructure risk. Each country is assigned a letter grade from A to E with E being most risky and a numerical score from 0 to 100 with 100 being most risky, for each of these categories, plus an overall risk assessment grade.[51] The Economist Intelligence Unit ranking is used in Table 4. Another risk ranking alternative considers a country's labor rates, unemployment rates, industrial production growth, inflation, gross domestic product growth, and literacy rates and assigns a risk ranking from 1 to 16, with 1 being the least risky.[52] This could be an alternate ranking to consider for risk level. Whichever ranking is used, companies need to be aware of what the risks are. These ranking systems can provide useful relative data, but specific risks should also be looked at prior to selecting a cost-reduction option. Managing risks is an important part of any supply chain strategy and understanding the risks involved in each option is an important factor in making sourcing decisions.

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[51] "The Economist Intelligence Unit." The Economist. 20 Mar. 2008 <www.eiu.com>.
[52] Vasovski, Steven. A Global Sourcing Strategy for Durable Tooling. Massachusetts Institute of Technology. Cambridge: Massachusetts Institute of Technology, 2006.

Ease of implementation can be ranked by the type of changes that will be necessary, such as process changes versus cultural or organizational changes. Timeline can be tailored to fit the pace of the industry, and is adjusted in Table 4 to reflect the long timelines within the jet engine manufacturing industry. By tailoring Table 2 to fit an industry and company's needs, this tool is an effective method of comparing cost-reduction alternatives.

Given the rankings created in Table 3, it may be tempting to add up the rankings to provide a total score for each alternative, but this is not a good means of evaluating cost-reduction alternatives. The table is intended to provide comparisons between alternatives within each category. As stated previously, the importance of the six categories will change depending on the situation. Each alternative should be evaluated with regards to its overall fit with company goals.

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5. Evaluating Low-Cost Sourcing as a Cost-Reduction Alternative

Low-cost sourcing can be an attractive option, but the costs, benefits, and risks must be weighed carefully in each situation to determine if this is a viable option. This section will discuss various options available for low-cost sourcing; the cost savings, expenses, and investments procurement managers should consider; and some of the key risks and benefits associated with low-cost sourcing. This section is intended to help managers answer the question 'Is low-cost sourcing right for my company?' Section 6 will discuss how to select the right method of low-cost sourcing.

5.1. Options

The benefits of low-cost sourcing can be achieved in a variety of ways. Low-cost sourcing does not always need to mean moving work to a manufacturing facility in China or India. The following common low-cost sourcing options will be discussed and evaluated herein:

1. Create low-cost partnerships with current suppliers;
2. Find or create a domestic low-cost source; and
3. Develop, partner with, or purchase suppliers in low-cost areas.

Low-cost sourcing has numerous variables that can be adjusted depending on the situation, which can make this a complex cost-reduction alternative. Even within each of these options there are various issues to consider, which will be discussed more thoroughly in Section 6.

Creating low-cost partnerships with current suppliers is an attractive low-cost sourcing option since the company is already familiar with the supplier. The partnership could consist of having work transferred from a supplier's domestic or high-cost manufacturing facility to an existing facility in a low-cost area. Another option is to work with a current supplier to have it set up a new facility or to purchase an existing facility in a low-cost area. Risk-sharing could be structured into the partnership as necessary. The important thing with this option is to ensure that the partnership is structured to align and meet the goals of both parties.

Finding or creating a domestic low-cost source is also an attractive option since this eliminates the need to move work overseas. A domestic low-cost source could be a supplier in a low-cost state or city, or it could be a supplier not in a low-cost area that has managed to reduce costs to provide a low-cost product.

Developing, partnering with, or purchasing suppliers in low-cost areas is probably the most involved option. This option requires dealing with a country and customs that the company may not be familiar with. It involves forging a relationship with a new supplier within the customs of that country. In this case the supplier may not be familiar with western aerospace work, and must be developed before work can be produced there.

In evaluating low-cost sourcing as a cost-reduction alternative, all three of the options discussed herein should be considered. Each option has its own impact on cost considerations, benefits, and risks. These will be discussed in the following sections.

5.2. *Cost Considerations*

The cost benefits of low-cost sourcing are difficult to interpret since costs are reduced in some areas and increased in completely different areas. The primary savings seen with low-cost sourcing are labor costs and overhead costs, including electricity, water, and space. Low-cost sourcing does not greatly affect materials costs. Fully loaded wage rates can be as low as $1 to $2 dollars per hour in some low-cost countries, compared with wage rates of approximately $15 to $25 per hour in the United States.[53] Low-cost sourcing realizes the best savings potential for part populations with high value-added costs. Companies that efficiently take advantage of low-cost sourcing can see cost reductions of up to 20 to 40 percent in total landed cost.[54]

Some of the increased expenses that need to be considered with low-cost sourcing include taxes, shipping, increased inventory holding costs, and on-going coordination costs. Investment costs required to begin work with a new supplier may include money for tooling, equipment, engineering qualification, training, permits, relocation expenses, insurance and transportation, contract termination costs, and other set-up costs.[55] There may be costs associated with building up the infrastructure of the low-cost area. Investment is required to identify and evaluate potential low-cost sourcing suppliers and to build relationships with these suppliers.

Numerous assumptions about safety-stock levels, taxes, and other financial data need to be made in order to compare investment and ongoing costs with anticipated savings. These assumptions are often specific to the industry, the company, supplier, and country. In making these assumptions, a company should ensure that the assumptions are reasonable and consistent. Companies should also track projects to test these assumptions and revise future considerations as necessary.

Low-cost partnerships with current suppliers have appeal since the company is familiar with the supplier, and the supplier is familiar with the company's work. Current suppliers are familiar with

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[53] Bhattacharya, Arindam, Thomas Bradtke, Jim Hemerling, Jean Lebreton, Xavier Mosquet, Immo Rupf, Harold L. Sirkin, and Dave Young. Capturing Global Advantage: How Leading Industrial Companies are Transforming Their Industries by Sourcing and Selling in China, India, and Other Low-Cost Countries. The Boston Consulting Group. Boston: The Boston Consulting Group, Inc., 2004.

[54] Bhattacharya, Arindam, Thomas Bradtke, Jim Hemerling, Jean Lebreton, Xavier Mosquet, Immo Rupf, Harold L. Sirkin, and Dave Young. Capturing Global Advantage: How Leading Industrial Companies are Transforming Their Industries by Sourcing and Selling in China, India, and Other Low-Cost Countries. The Boston Consulting Group. Boston: The Boston Consulting Group, Inc., 2004.

[55] Kary, Jason R. Advanced Aerospace Procurement Models with Sensitivity Analysis and Optimized Demand Allocation. MIT Leaders for Manufacturing Program. Cambridge: Massachusetts Institute of Technology, 2006.

western aerospace requirements, which would reduce the costs associated with developing a new manufacturing facility. This eliminates the need to build new relationships, and the level of effort required to identify and evaluate this option is likely reduced. The supplier may be willing to share or cover costs such as tooling and the engineering support required to develop the low-cost facility. One disadvantage is that the current supplier will know current part prices and may have better leverage to keep a larger percentage of the profits gained from this venture, especially if the supplier currently has high bargaining power.

Finding or creating a domestic low-cost supplier also has appeal since logistics costs would be reduced. Costs such as shipping, inventory holding costs, and on-going coordination costs will likely be less than for an overseas location. Domestic facilities are more likely to be familiar with western manufacturing requirements, making development costs such as engineering support less expensive. One disadvantage here is that it may be difficult to ensure that the facility remains low cost. If a low-cost casting facility were set up domestically, chances are that a competing supplier would attempt to purchase the facility to eliminate the competition and then increase prices. If this did not happen, then a competing company might attempt to purchase the low-cost facility or offer to pay a slightly higher price for work, thus taking capacity away from the company. Prices for the company could then be raised, leaving the situation the same as before.

5.3. Benefits

Low-cost sourcing has numerous benefits that have fueled its recent popularity. Although lower labor rates are the primary driver of low-cost sourcing, additional benefits can be realized as well. This section will discuss some of the primary benefits besides saving money that low-cost sourcing can provide in this industry and the ways in which these benefits differ between the three low-cost sourcing options.

International low-cost sourcing provides direct access to new and emerging markets.[56] This can be a definite advantage in the aerospace industry. Countries looking to purchase or upgrade a fleet of aircraft may be more likely to purchase from companies with significant business within that country. In some countries offset requirements might be a part of a purchase transaction, requiring the company to produce a certain amount of the work within that country.

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[56] Bhattacharya, Arindam, Thomas Bradtke, Jim Hemerling, Jean Lebreton, Xavier Mosquet, Immo Rupf, Harold L. Sirkin, and Dave Young. Capturing Global Advantage: How Leading Industrial Companies are Transforming Their Industries by Sourcing and Selling in China, India, and Other Low-Cost Countries. The Boston Consulting Group. Boston: The Boston Consulting Group, Inc., 2004.

Low-cost sourcing can provide companies with access to new technologies or capabilities.[57] By integrating these technologies and capabilities, a company could enjoy a competitive advantage over its competitors. The jet engine industry is highly regulated, which does limit the amount to which a company can integrate new technologies encountered. In areas such as castings, current suppliers are believed to have the best technology currently available, as evidenced by the fact that these suppliers can currently make parts that no other suppliers can make. There are costs and cultural shifts associated with getting new technologies approved that may be prohibitive. Despite this, a company should not rule out this possibility, and should carefully evaluate and consider new technologies and capabilities as appropriate for their business. Doing so could create a new process method that reduces costs or improves performance.

Another benefit that a company could realize from low-cost sourcing both domestically and internationally is government incentives. Tax rates and natural or labor resources available in a country could present an advantage. Some companies in low-cost countries are deliberately making deals or setting up tax or import duty incentives to entice foreign business.[58]

By moving work to a new, low-cost supplier, the company can move work from those suppliers that currently enjoy high supplier bargaining power, thus improving the company's bargaining position. High supplier power results largely from the fact that current suppliers do not have a lot of competition. Low-cost sourcing introduces more supplier competitors. Current suppliers that before had no need to decrease their prices might now face the decision to lower prices or see the work move overseas. Having more than one capable supplier also enables the company to dual-source parts if desired. This would allow for more flexibility in the supply chain.

The first low-cost sourcing alternative, partnering with current suppliers, produces most of the benefits discussed in this section. The one benefit that is in question is the ability to decrease supplier power. If the partnering supplier currently has high supplier power, then this action will increase that power. The company will become even more dependent on that supplier.

The second low-cost sourcing alternative, domestic low-cost sourcing, does not produce most of the benefits discussed within this section. Since work is done within the country, there is limited new access to direct or emerging markets. There is less chance of discovering new technologies or

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[57] Bhattacharya, Arindam, Thomas Bradtke, Jim Hemerling, Jean Lebreton, Xavier Mosquet, Immo Rupf, Harold L. Sirkin, and Dave Young. Capturing Global Advantage: How Leading Industrial Companies are Transforming Their Industries by Sourcing and Selling in China, India, and Other Low-Cost Countries. The Boston Consulting Group. Boston: The Boston Consulting Group, Inc., 2004.

[58] Bhattacharya, Arindam, Thomas Bradtke, Jim Hemerling, Jean Lebreton, Xavier Mosquet, Immo Rupf, Harold L. Sirkin, and Dave Young. Capturing Global Advantage: How Leading Industrial Companies are Transforming Their Industries by Sourcing and Selling in China, India, and Other Low-Cost Countries. The Boston Consulting Group. Boston: The Boston Consulting Group, Inc., 2004.

capabilities. The benefit of government incentives is probably lessened, although some incentives may be provided at the state or city level. Creating a new domestic source would increase competition, which could reduce supplier power. The company would need to be careful that it did not simply create another company with high supplier power.

The third low-cost sourcing alternative, developing, partnering with, or purchasing a supplier in a low-cost area, does produce the benefits described within this section.

In addition to the cost-reduction potential, low-cost sourcing offers a company numerous other benefits. It provides access to new and emerging markets and to new technologies and capabilities. Low-cost sourcing enables companies to take advantage of government incentives and to increase competition within the supply chain.

5.4. Risks

Although low-cost sourcing is an attractive cost-saving alternative, there are risks associated with sourcing work in low-cost areas. This section will discuss some of the primary risks involved, what actions can be taken to minimize those risks, and how these risks vary among the three low-cost sourcing alternatives.

5.4.1. Losing Money

The first and primary risk involved with low-cost sourcing is that the company will not actually save any money. Given the amount of effort required to find, evaluate, and develop low-cost sources, this is a very real threat. Suppliers may not be able to achieve the price reductions promised. Development could take longer and cost more than anticipated. Poor quality could require additional costs in rework and scrap. The supplier may not actually be able to make the parts due to a lack of capability, lack of equipment, or export restrictions. All of the assumptions that were initially made could be called into question.

The threat of losing money is made more dangerous when companies "select" assumptions that will produce the cost savings desired. In order to minimize this threat, companies should base assumptions on the best possible data and not adjust these assumptions to produce a more favorable result. Companies should track the assumptions that were made on approved projects to gauge their validity and adjust future assumptions accordingly. It is imperative the companies consider all costs involved in making low-cost sourcing decisions. This can be aided through the use of a total landed cost model. Low-cost sourcing decisions should be consistent with the overall supply chain strategy of the company.

5.4.2. Developing a Supplier for Competitors

Once a supplier in a low-cost area has been successfully developed, that supplier could become a target for competitors. The company that spent the development costs is looking to recoup those costs and will demand low pricing. A competitor that has no money invested is primarily concerned with having a lower price than the incumbent supplier. If a competitor came in and offered to pay more than the original company, the supplier's capacity may be taken up by the competitor. In another scenario, the competitor could come in and purchases the supplier. Contracts made with companies in other countries can be difficult to enforce, which could enhance this threat.

The best way to avoid this debacle is to prepare for it in advance. It is not a question of if a competitor will try to utilize the supplier, it is a question of when, and how successful the competitor will be. The company needs to form a bond with the supplier that will ensure the supplier's loyalty for some period of time. In some cultures relationships can be an important aspect of supplier loyalty. If this is the case, the company should focus heavily on developing a strong relationship with the supplier. In other cultures the supplier will only care about who is willing to pay the highest price. Locking the supplier into a long-term contract or forging a partnership or joint venture with the supplier may be ways of forestalling the competition and ensuring exclusivity or priority. Additional support and development might entice the supplier to remain loyal. Above all, a company must be familiar with the cultures and customs of the supplier's country to know what will and will not work in this regard. Are contracts strictly followed in this country? Are relationships strong enough to maintain loyalty? The company should keep in mind that as the country develops, these customs may change. The bond between supplier and company must be strong enough to withstand those changes.

5.4.3. Lack of Manufacturing Expertise

Suppliers in low-cost areas may be unfamiliar with western aerospace requirements, and would thus need to develop new manufacturing and testing policies and procedures to meet these requirements. The company would hold the primary role in assisting suppliers to set up these policies and procedures. However, the company may have been outsourcing this work for years and may no longer have the manufacturing expertise in-house to assist the new suppliers. This will slow down the development process, increasing both costs and timeline. The new suppliers will be starting from scratch without the benefit of the years of experience that have enabled current suppliers to go down the learning and experience curves and achieve greater efficiencies and cost reductions.

This is a very real concern, and companies need to ensure that the necessary manufacturing expertise is made accessible. This could mean hiring employees from current suppliers who have this expertise. Partnering with current suppliers would ensure this expertise. The company must be careful

not to confuse the ability to make a part with the knowledge of how to manufacture that part on a full-scale production level. Once this manufacturing expertise has been obtained, it must be utilized to develop the new suppliers.

5.4.4. Backlash from Current Suppliers

Exiting current suppliers will have repercussions that must be considered. If low-cost sourcing were as simple as switching work from a current supplier on day one to a new supplier on day two, then this would be minimized. Unfortunately, nothing is ever that simple. Chances are that not all work will be taken from a current supplier at the same time. Dual sourcing may be utilized to minimize risks. The cost for work remaining at that supplier could increase. This could be due to a smaller volume discount or because the supplier knows that the work will likely be taken away anyway and wants to make as much profit beforehand as possible. Certain parts in this industry are unattractive to suppliers. They may be difficult to make or may just have low profit margins and low volumes. The current suppliers for those parts may refuse to make them anymore once work starts to be taken away. The current supplier may be kept as a dual source with lesser volume, which would almost certainly result in a price increase. Ramp-up of the new supplier must be concurrent with ramp-down of the current supplier. If the new supplier is late in ramping up, the old supplier may have other commitments and be unwilling or unable to continue to produce the parts. As the supplier starts to have less work, the relationship will likely deteriorate, and the supplier could be less willing to work with the company when necessary to expedite work or change schedule requirements.

This risk cannot be eliminated, so it must be minimized and managed. Business cases and plans for transitioning work must explicitly consider the previous suppliers and their potential reactions. Being honest with current suppliers can help to maintain trust between the two parties. Current suppliers could be given the option of matching or undercutting the low-cost supplier's prices. Getting as much information as possible regarding the intended response from current suppliers will help a company to prepare. Setting up risk-sharing with the new supplier in the event that the supplier is late in ramping up may help to protect the company. In this case, the company needs to ensure that the supplier has the ability to uphold its end of the bargain.

5.4.5. Political and Economic Stability

Doing business in low-cost countries introduces political and economic risks associated with those countries. As more businesses recognize the advantages of moving to these countries, the economy is strengthened and grows, sometimes at unsustainable rates. As the economy grows, wages will likely increase, which could decrease the cost advantage seen from low-cost sourcing. Currency trade values could shift, affecting the company's profits. Some of these countries have unstable governments.

Production could be affected by changing policy decisions, by events such as a dock-workers strike, or by large-scale political upheavals or wars.

There is little a company can do to control the political and economic risks of any one country, so to the company must do what it can to minimize the risks to itself. Dual sourcing among two or more countries is one good way to address this risk. A political or economic downturn in one country could be handled by maintaining the ability to flux capacity at and shift work to the facility in the other country. It is important for the company to recognize the political and economic risks within a country prior to sourcing there and to remain informed about those risks as work proceeds. The company must have a mitigation plan and be prepared to act should anything occur to affect the supply chain.

5.5. Summary

The decision of whether to pursue low-cost sourcing is one of estimating the risk-rewards ratio, determining the risk tolerance of the company, and establishing the fit with the company's overall supply chain strategy.

6. Evaluating Low-Cost Sourcing Options

The ideal low-cost sourcing solution is to find a supplier fully capable of currently doing the company's work, fully motivated to do so, in a low-cost area, with available capacity, that competitors are not yet using. The chances of this happening are small as multiple companies scour the world trying to find the ideal solution. The goal of low-cost sourcing is to identify the best available compromise. This section will discuss how a company should evaluate low-cost sourcing options to make that compromise.

6.1. Filters

Once low-cost sourcing has been decided upon as a cost-reduction solution, the big questions become:

- What to source?;
- Where?; and
- Why?

Within the question of 'Why?' are the questions of 'How?', 'When?', and 'How do you manage these transitions?' In order to answer these questions, various filters were created to parse out the parts, countries, and companies that represent the best low-cost sourcing opportunities. These filters were derived from interviews with a number of current and previous procurement managers within UTC and its supply base and are summarized in Table 5. This section will discuss these filters and their use in detail.

Part Filters	Country Filters	Company Filters
Exportability	Strategic Importance	Strategic Importance
Complexity	Offset Requirements	Hard Costs
Material Type	Hard Costs	Quality Performance
Business Case	Political Stability	Delivery Performance
Annual Volume	Economic Stability	Financial Stability
Demand Variation	Access to Technical Capability	Management Attitude
Value Stream Considerations		Technical Capability
Current Contracts, Supplier Relationships, Strategy, Etc.		Manufacturing Capability
		Procurement System
		Available Capacity
		Lead Time
		Lean Culture

Table 5: Filters to Evaluate Low-Cost Sourcing Opportunities

6.1.1. Part filters

The first step in creating a low-cost sourcing strategy is to determine which parts are eligible for low-cost sourcing and which parts it makes sense to source in a low-cost area – this answers the question of 'What to source?' In order to do this it is necessary to look at the company's parts list and sort out which parts meet the desired criteria. The following list of filters was created that cover the main parts criteria that need to be considered before slating a part for low-cost sourcing:

- Exportability;
- Complexity;
- Material type;
- Business case;
- Annual volume;
- Demand variation;
- Value stream considerations; and
- Current contracts, supplier relationships, strategy, etc.

Each filter should be considered to be one aspect of the greater sourcing decision. Many of the filters affect each other. No one filter can be viewed in isolation. The relative importance of the filters will vary based on the situation and low-cost sourcing goals. This section will discuss each filter and how it relates to low-cost sourcing decisions.

Exportability: The exportability of a part refers to whether or not a part can be exported to another country. There are various levels of exportability, ranging from parts that are freely exportable to any country to parts that absolutely cannot be exported outside of the country. Between these two extremes are parts for which an export license would be required. The level of effort required to put together an export license application, and the chance of actually obtaining an export license would vary depending on the part and the intended supplier company and country. All of these factors should be considered in determining which parts should be considered for low-cost sourcing. When putting together a low-cost sourcing plan, a company should select parts based on what is currently exportable and what the company believes will be exportable in the future.

Complexity: The complexity of a part refers to how difficult it is to manufacture that part. The complexity could affect the exportability, for example, if a part is made with a controlled technology. Part complexity ranges from parts that any supplier could make to parts that only one supplier in the world could make. A company should select parts for its low-cost sourcing plan based on what parts low-cost suppliers are currently able to manufacture and on what parts a supplier could be developed to be

able to manufacture going forward. The level of complexity selected should match the company's low-cost sourcing strategy.

Material type: The material type of a part refers to the base material of the alloy or substance of which the part is made. The material type would depend on the part type. This factor could be important if the low-cost sourcing strategy is to reduce the cost of manufacturing titanium parts, for example. Material type is related to exportability and complexity since the export of some materials is regulated, and some materials are harder for suppliers to work with. The company should keep these factors in mind in developing a low-cost sourcing strategy.

Business case: The business case for a part encompasses the financial and strategic reasons that a part would be included in a low-cost strategy. One component of the business case is the amount of value-added costs included in the part cost. As discussed previously, value-added costs are the main basis of cost reductions achieved with low-cost sourcing, so parts with negligible value-added costs do not make good candidates for low-cost sourcing. Another component of the business case is the shipping costs that will be incurred in transportation. For example, parts with high weights or volumes may have high shipping costs and not be good for inclusion in a low-cost sourcing plan. The business case to include or exclude a part depends heavily on what the goals of the low-cost sourcing effort is. A company needs to ensure that the business case for moving a part makes sense before including it in a low-cost sourcing plan.

Annual volume: The annual volume is the average estimated part quantity that is to be produced in upcoming years. Annual volume is most important in the development phase of a new supplier. Once the development phase is complete, the supplier is expected to produce parts regardless of the annual volume. In setting up a development plan for a new supplier it is useful to select parts that have a volume adequate for the supplier to gain knowledge and improve efficiencies through part production.

Demand variation: Demand variation refers to how much the production schedule for a part fluctuates over time. Like the annual volume, demand variation is less important for a fully developed supplier. In setting up a development plan, a steady volume of parts is preferable from a learning perspective for the new supplier.

Value stream considerations: This filter refers to the locations where a part is coming from and going to before and after the low-cost source. This filter relates to managing the entire value stream rather than the individual role the supplier will fill. If the previous processing location is a machining facility in China, and the next processing location is an assembly facility, also in China, then it may make an obvious case to source this process in China as well.

Current contracts, supplier relationship, strategy, etc.: This filter refers to contracts a part is under with a current supplier, the relationship between the company and the current supplier, the strategy

the company is pursuing, and other factors that the company feels might be relevant to the sourcing decision. A company should consider when a part will be available for sourcing by another supplier, or the consequences of breaking the current contract. A company may have strategic reasons for keeping certain suppliers and not want to move parts away from those suppliers for fear of damaging the relationship. A company must consider whatever other strategic goals it has that might affect the part population for low-cost sourcing.

6.1.2. Country filters

The next step in developing a low-cost sourcing strategy is to determine which countries to target for sourcing work – to answer the question of 'Where to source?' This decision requires looking at how relevant factors differ in the countries under consideration. The following list of filters covers the criteria that should be evaluated in considering countries for low-cost sourcing:

- Strategic importance;
- Offset requirements;
- Hard costs;
- Political stability;
- Economic stability; and
- Access to technical capability.

As with the part filters, the country filters are interrelated, and they are related to the part filters. This section will discuss each country filter and how it relates to low-cost sourcing decisions. In many cases the sourcing location will be determined more by the company than by the country. In those situations this section can still be utilized to assess the risks associated with procuring work from that country.

Strategic importance: This filter refers to any strategic reason why a company would want to proactively place work within a certain country. This could include a plan to create a local presence in an emerging market. Another reason could be for value stream considerations, where complementary parts of the value chain for a part population are located within that country.

Offset requirements: Offset requirements are the obligations a company has to do a set amount of work within a specified country due to a work contract within that country. In instances where offsets are required, a company might strongly prefer to source within the offset country if possible in order to meet obligations.

Hard costs: Hard costs refer to the tangible costs incurred in having work performed in that country. This would include costs such as taxes, shipping, and duties. This would not include costs such as inventory holding costs or quality and rework costs, which are considered soft costs and are more a

result of the company and supply chain design then of the sourcing country. Hard costs are unique to the country itself. These costs could vary based on the section of the country being considered. In these cases, the various sections should be considered as two different areas under this filter. Hard costs can influence sourcing decisions when there are significant differences in hard costs among countries or areas.

Political stability: Political stability refers to how stable the government and political setting are within the country. A company should fully understand the political risks present in the areas where sourcing is being considered. Political risks may not keep a company from sourcing within a certain country, but the company should be aware of the risks it is undertaking. Then a contingency plan to manage these risks should be developed.

Economic stability: This filter deals with how stable the economic situation of the country is. Factors that influence the stability of the economy include the rate of economic growth, the stability of the local currency, and government policies. Economic stability is important in an area where work is being performed since a crash or boom in the economy could drastically alter prices and negate any cost savings that had been achieved. In the worst case, the sourcing facility could be forced to shut down.

Access to technical capability: Access to technical capability refers to the ability of the country to access the technologies necessary to perform the work. The technical capability does not need to reside within the country, but the capability must be accessible. One means of accessing a technology could be through an export license from another country. Whether or not the country can get the necessary technology is key to being able to conduct work within that country. By determining early in the sourcing process whether a country can gain access to technical capability, less time and energy is wasted on evaluating unsuitable locations.

6.1.3. Company filters

After determining which countries to target and to eliminate, the next step is to determine which companies within those countries should be targeted to source work – to more specifically answer the question of 'Where to source?' The following list of filters covers the factors to be considered in evaluating companies for low-cost sourcing opportunities:

- Strategic importance;
- Hard costs;
- Quality performance;
- Delivery performance;
- Financial stability;
- Management attitude;
- Technical capability;

- Manufacturing capability;
- Procurement system;
- Available capacity;
- Lead time; and
- Lean culture.

This section discusses each company filter and how it relates to low-cost sourcing decisions. Again, all of the filters are interrelated and are related to the part and country filters. If a potential supplier company is promising enough, additional country risks may be deemed acceptable.

Strategic importance: As with the country filter, strategic importance refers to any reason consistent with the company's supply chain strategy for wanting to place work with a certain supplier. This could include wanting to obtain a technology from a supplier or wanting to partner with a supplier. Reasons such as these could impact sourcing decisions. However, even if a supplier is a perfect fit with a strategic goal, the company should still evaluate the other filters described herein. The company may determine that the intended goal is worth risks in other criteria, but those risks should still be identified and evaluated prior to making the final decision.

Hard costs: Hard costs refer to the tangible costs of having work performed within that supplier company (not including costs that depend primarily on the country). Examples of costs included in this filter are materials costs, value-added costs, and development costs. These costs can vary greatly by company and are often the main deciding factors in sourcing decisions. This filter definitely needs to be considered, but again, this filter cannot be considered in isolation, but rather as it fits with the other criteria.

Quality performance: Quality performance refers to the quality level of parts produced by the supplier. The primary indicator of quality performance by a supplier is yield. This indicator should be viewed with an eye on how difficult the process is – more difficult processes tend to have lower yields. The company should consider this filter in conjunction with the complexity of the process to be outsourced. It may be possible to increase yields through supplier development. Initial yields provide an idea of where the supplier is currently at and what level of development would be required to obtain acceptable yields. This may also indicate how much prominence quality has in the supplier's culture. If quality is not a part of the supplier's culture, then a culture change would be necessary on top of supplier development. This could increase development costs and delay implementation.

Delivery performance: This filter evaluates the supplier's historical on-time delivery rates. This can provide an indicator of how well the supplier operates to a schedule and whether this is a part of the supplier's culture. Like quality performance, delivery performance can likely be improved by development, but if this is not part of the supplier's culture there could be considerable resistance.

Financial stability: This filter refers to how secure a supplier is fiscally. This can be important if the supplier is at risk of bankruptcy or being bought out. This can also be important in terms of the amount of cash flow a supplier has to invest in development and equipment. A supplier should be sound enough financially to withstand the cycles of the aerospace industry and to adjust to fluctuating demand schedules.

Management attitude: Management attitude refers to how management views the low-cost sourcing opportunity. A supplier could have great technical and manufacturing capability, but if the supplier is not willing to work with the company, that supplier could still be a bad selection. Management attitude includes the willingness of managers to work with the company, to be willing to invest in development and be willing to learn, to meet delivery and performance goals, and to adhere to all other aspects relevant to the transaction. Suppliers with management that is fully invested in the relationship can be a great asset to the success of the venture.

Technical capability: This filter refers to the level of a supplier's current technical competencies. Knowing the current technical capability of a supplier is important in determining the level of development that would be required. Evaluating a potential supplier's technical capability can also provide a means of determining if that supplier has a technology that would be of interest to the company. If the supplier does not currently have the necessary technological capability, a feasible development plan agreed upon by both parties is imperative to achieving the necessary capabilities and achieving success in the low-cost endeavor.

Manufacturing capability: Manufacturing capability refers to the supplier's competency with manufacturing. This is different than the supplier's technical capability. A supplier could have the technology to produce a part without having the know-how to be able to manufacture that part at a full production level. Manufacturing capability includes the ability to produce a part quickly, cheaply, uniformly, efficiently, and of high quality. As discussed previously, this is one area where the company may not have the necessary knowledge to be able to develop the supplier since the company may not have the manufacturing capability in-house. If the supplier lacks the necessary manufacturing capability, it is important that a plan for developing the capability is drawn up and agreed upon by both parties.

Procurement system: This filter evaluates the supply chain and policies of the supplier to determine if they are in keeping with anticipated requirements. In the aerospace industry, parts must be tracked the entire length of the supply chain. It is therefore necessary that a supplier's supply chain meets, or has the capability of being developed to meet, these requirements.

Available capacity: This refers to the amount of work that the supplier can take on in addition to its current workload. The ideal situation is for the supplier to have enough capacity to take on the desired work, but enough current work such that the supplier is not completely dependent on the company. A

supplier at or near full capacity is not able to handle demand surges and is more prone to schedule delays since downtime cannot easily be made up. A supplier with a lot of excess capacity is risky since lulls in demand could hurt the supplier financially and the supplier would need to make up all overhead costs with the company's work. If a low-cost sourcing plan is based on plans to increase capacity, those plans should be evaluated with regards to timeline and feasibility. The amount of free capacity desired depends on the company's plans for the supplier.

Lead time: This filter refers to how long it takes the supplier to produce a part from the time the order is placed. This could depend on a number of variables such as the amount of inventory held and process efficiencies. The lead time influences the responsiveness of the company's supply chain. If the supplier's lead time is unacceptable to the company, a plan should be put in place to reduce lead times.

Lean culture: This refers to how well the culture within the supplier currently looks towards continuous improvement practices. The company can help implement lean initiatives within suppliers, but it is more difficult to instill a lean culture if one was not already in place. Having a lean culture is important in improving process efficiencies and reducing costs.

6.1.4. Summary

The part, country, and company filters make up a framework for evaluating low-cost sourcing opportunities. These filters, as summarized in Table 5, should be used as guidelines for ensuring that the company's low-cost sourcing decisions are in line with the company's supply chain strategy.

6.2. Domestic Low-Cost Sourcing Analysis

International sourcing is not the only means of low-cost sourcing. Certain parts cannot be sourced internationally, and for some parts international sourcing does not make sense. For these parts it may make sense to consider domestic low-cost sourcing.

Domestic low-cost sourcing can be achieved when a company locates or creates a supplier in a low-cost region within the country, or when a supplier's efficiencies enable it to be a low-cost source despite its location. This analysis evaluates the option of selecting a domestic low-cost area based on external costs rather than efficiencies within the supplier's facility.

A domestic low-cost sourcing model was created to evaluate relevant factors in determining what the best sourcing location would be. This section describes the domestic low-cost sourcing analysis and model.

6.2.1. Analysis

Six factors were identified in conducting the domestic low-cost sourcing analysis as being important variables in sourcing parts. The following list of factors was developed through discussions with procurement and manufacturing personnel at P&W:

- Labor costs;
- Health care costs;
- Energy costs;
- Cost of living;
- Tax structure; and
- Education level.

This list encompasses the main criteria in the aerospace industry that procurement mangers should look for in sourcing work. This list may be revised to include additional factors that a company deems to be important, such as access to a major airport or railway for transportation of goods. Labor, health care, and energy costs directly affect the company's expenses and are important factors in minimizing costs. The cost of living of an area is an indicator of how expensive it is to do work in that area. The tax structure of an area affects a company's net profits. The education level of people within an area indicates the availability of educated personnel that could be placed in the workforce and can affect the quality and efficiency of work performed. In selecting an area to create a domestic low-cost facility, a company would look to minimize labor, health care, and energy costs and the cost of living, and to select the most favorable tax structure and highest level of education.

Data on each of the six factors were collected for each of the states and for the District of Columbia. Annual wages for each state from the United States Bureau of Labor Statistics were used to indicate labor costs. Hospital costs from the Kaiser Family Foundation provide an indicator of health care costs. Energy costs were collected from the United States Department of Energy. Housing costs from the United States Census Bureau were used to indicate the cost of living for each state. Tax structure was determined by using two data sets: the tax rate from the Federation of Tax Administrators and the state business tax climate index from the Tax Foundation. Data on education level were obtained from the National Center for Educational Statistics. The data used in this analysis are included by factor in Appendix A.

6.2.2. Model

A domestic low-cost sourcing model was developed to assist procurement managers in evaluating states based on the six criteria discussed above. The model allows procurement managers to weight the

relative importance of the six criteria for a given part population. The data collected for these criteria are then evaluated within the model to provide a list of recommended states for sourcing that part population.

The model works by sorting the state's data for each criterion from most to least preferable and assigning a respective ranking to each state from 1 to 51. For tax structure, the model averages the state's two ranking scores to provide one overall ranking score. The procurement manager weights each of the six criteria in terms of importance for a part population, from one to five, with one being the most important. For example, most casting processes are much more labor intensive than forging processes. Therefore labor might be weighted 1 for castings, and 3 for forgings. The weights compare directly within each part type. A weight of 1 in labor costs for castings compared to a weight of 3 in energy costs indicates that labor costs are 3 times more important than energy costs to the procurement manager for castings. The model multiplies the state rankings in each category with the category weights and outputs a rank order of the states with the lowest scores, indicating that these states would be the best locations, based on the selected criteria, to set up a domestic low-cost sourcing facility.

The primary input screen for the model with potential rankings for various part types is shown as Figure 1. The inputs into the model are the weights for each of the factors. The model outputs are the ranking of recommended states.

Relative Importance of Various Factors by Commodity (Scale of 1 - 5)

Factors	Fabrications	Composites	Forgings	Castings	Machining
Labor Costs	2	2	3	1	1
Cost of Living	3	3	3	2	3
Heath Care Costs	3	3	3	2	3
Energy Costs	3	3	1	3	4
Education	2	2	4	3	2
Tax Structure	4	4	2	3	4

1 - most important
5 - least important

Recommended States	Fabrications	Composites	Forgings	Castings	Machining
1	South Dakota	South Dakota	South Dakota	South Dakota	South Dakota
2	Wyoming	Wyoming	North Dakota	North Dakota	Wyoming
3	North Dakota	North Dakota	Montana	Wyoming	North Dakota
4	Montana	Montana	Kansas	Kansas	Kansas
5	Kansas	Kansas	Nebraska	Montana	Montana

Figure 1: Domestic Low-Cost Sourcing Model

6.2.3. Limitations

This model can be used as a guideline, but the model does have limitations. The ranking system the model uses treats the differences between consecutive states the same, regardless of the actual size of

the difference. For example, under cost of living, Louisiana, Wisconsin, and Oregon are ranked 7, 27, and 36, with median housing costs of just over $100,000; $150,000; and $200,000; respectively. Wisconsin is penalized with 20 ranking points for a $50,000 difference, making the total ranking almost four times worse than Louisiana's. In contrast, Oregon is penalized only 9 ranking points over Wisconsin for that $50,000 difference. Oregon's total ranking is less than twice Wisconsin's rank. The ranking system the model uses can unfairly penalize some states more than others.

The model currently utilizes only six factors, five of which are represented by a single, static, dataset. These factors were deemed to be the most important factors, but additional factors could be highly relevant given the situation and would need to be added into the model. The datasets for the six factors were selected to provide an easy indicator for a broad topic. A company may feel that other indicators and datasets are more relevant for a given situation. These datasets provide averages across states, but factors such as wages could vary greatly within the state.

There are additional factors that may be relevant for inclusion in the model depending on the situation. These factors could include access to a major airport or shipyard, environmental awareness and regulations, and relevant exposure and experience of the workforce.

6.2.4. Summary

Low-cost sourcing does not necessarily mean international sourcing. There are many reasons why domestic sourcing may be appropriate or necessary. Given one of these situations, low-cost sourcing can be done domestically by comparing costs and other relevant factors between states. The model described herein can be used as a tool for evaluating states. The model enables the user to weight the factors that are the most important in a sourcing decision for a part population. The output of the model is the states that best fit the selected criteria. This model has its limitations but can be a useful tool in making domestic sourcing decisions.

6.3. Lessons Learned

Once a sourcing decision has been made, a company can learn a lot about its decision-making process by continuing to re-evaluate that decision on an on-going basis. Companies and managers spend time on forecasts, plans, and looking forward. It can be difficult in the frenzy of deadlines and emergencies to remember that a lot can be gained from taking the time to look backwards. As has been discussed throughout this thesis, numerous assumptions are made regarding profitability, timeline, benefits, and risks before making sourcing decisions. Those decisions can have large consequences on the company's profitability, quality, and delivery performance. Some of these decisions have results that are better than anticipated, some run exactly as planned, and some wind up not meeting financial or schedule goals. By evaluating sourcing decisions and the assumptions that went into making them, a

company can test the wisdom of those decisions and the validity of the assumptions. This data can be used to improve the company's sourcing decision-making process, which could increase the percentage of the time that sourcing decisions meet or exceed expectations. This could result in the sourcing decision-making process itself becoming a competitive advantage for the company.

7. Conclusion

This section provides a summary of the research and analysis discussed herein and how this can be used to benefit procurement managers. Although this analysis was conducted based on castings and forgings in the jet engine manufacturing industry, the general framework and evaluation can be tailored to fit other part types and industries as well.

Cost-reduction alternatives should be a part of, not an addition to, the supply chain strategy. Multiple alternatives can and should be employed concurrently to reduce costs. Managers should take care not to try to fit one cost-savings solution to all problems. Potential cost-reduction alternatives should be evaluated with regards to cost-reduction potential, investment required, simplicity, risk level, ease of implementation, and timeline. The ability to measure these factors changes based on the alternatives involved and the factors in question. Risk level can be especially difficult to measure due to the intangibility and difficulty in measuring many of the risks involved. A careful evaluation of risks is necessary in evaluating cost-reduction alternatives. The evaluation factors suggested herein do not carry equal weight and should be evaluated both individually and holistically.

Low-cost sourcing is not a one-size-fits-all approach. When determining if low-cost sourcing is a viable option a company should fully evaluate all costs involved, the benefits of the options, and the risks that will be encountered. A framework was described herein for evaluating low-cost sourcing opportunities once this has been deemed to be a viable solution. This framework involves the utilization of various filters to screen parts, countries, and companies to create a low-cost sourcing plan. Managers can customize this framework based on the company's supply chain strategy to determine which solutions would be viable for a given situation. A model that provides recommended sourcing locations was developed to evaluate domestic low-cost sourcing options. Managers can also customize this model based on relevant supply chain strategy goals to compare domestic sourcing locations. The low-cost sourcing evaluation framework and the domestic sourcing model can be used as tools to aid low-cost sourcing decisions. These tools are meant to complement and aid the company's supply chain decisions. Companies should work to continuously improve their low-cost decision-making process by tracking decisions made and adjusting future decisions accordingly.

The key take-away is that companies need to carefully develop a supply chain strategy and then structure their organization and cost-reduction alternatives to be consistent with this strategy. Value stream management, a total landed cost model, the alignment of personnel incentives with company goals, and the frameworks and models developed within this thesis are tools that can assist companies with this goal.

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Appendix A: Domestic Low-Cost Sourcing Analysis Data

Rank	State	Mean Annual Wage
1	Mississippi	$ 30,460
1	South Dakota	$ 30,460
3	Arkansas	$ 30,870
4	Montana	$ 31,290
5	West Virginia	$ 31,440
6	North Dakota	$ 32,440
7	Oklahoma	$ 32,570
8	Louisiana	$ 32,900
9	Iowa	$ 33,250
10	South Carolina	$ 33,400
11	Alabama	$ 33,440
12	Kentucky	$ 33,490
13	New Mexico	$ 33,980
14	Tennessee	$ 34,240
15	Wyoming	$ 34,290
16	Nebraska	$ 34,300
17	Idaho	$ 34,810
18	Kansas	$ 34,960
19	Maine	$ 35,160
20	Indiana	$ 35,190
21	North Carolina	$ 35,520
22	Utah	$ 35,540
23	Missouri	$ 35,670
24	Florida	$ 35,820
25	Nevada	$ 36,000
26	Arizona	$ 36,260
27	Vermont	$ 36,350
28	Texas	$ 36,410
29	Wisconsin	$ 36,730
30	Georgia	$ 37,150
31	Ohio	$ 37,360
32	Pennsylvania	$ 37,580
33	Oregon	$ 38,570
34	Hawaii	$ 38,630
35	New Hampshire	$ 39,250
36	Rhode Island	$ 40,580
37	Illinois	$ 40,910
38	Michigan	$ 41,230
39	Colorado	$ 41,450
39	Virginia	$ 41,450
41	Minnesota	$ 41,510
42	Delaware	$ 41,680
43	Washington	$ 42,910
44	Alaska	$ 43,920
45	Maryland	$ 44,030
46	California	$ 44,180
47	New Jersey	$ 45,450
48	New York	$ 45,820
49	Connecticut	$ 45,970
50	Massachusetts	$ 47,340
51	District of Columbia	$ 61,500

Labor Cost Rankings[59] [60]

[59] Adapted From: "Occupational Employment Statistics." Bureau of Labor Statistics. United States Department of Labor. 17 Aug. 2007 <http://www.bls.gov/oes/>.

[60] 2006 Wage Data.

Rank	State	Expenses per Inpatient Day
1	South Dakota	$733
2	Wyoming	$805
3	Montana	$814
4	North Dakota	$898
5	Mississippi	$1,021
6	Iowa	$1,036
7	Kansas	$1,055
8	Nebraska	$1,066
9	West Virginia	$1,113
10	Vermont	$1,166
11	Kentucky	$1,194
12	Alabama	$1,198
13	Georgia	$1,202
14	Tennessee	$1,234
15	Arkansas	$1,238
16	Louisiana	$1,293
17	Minnesota	$1,300
18	Hawaii	$1,310
19	North Carolina	$1,320
20	Oklahoma	$1,332
21	Virginia	$1,394
22	Wisconsin	$1,458
23	Michigan	$1,460
24	South Carolina	$1,465
25	Idaho	$1,484
26	Florida	$1,497
27	Pennsylvania	$1,500
28	Maine	$1,528
29	New York	$1,539
30	Missouri	$1,560
31	Indiana	$1,569
32	New Hampshire	$1,627
33	Texas	$1,636
34	Illinois	$1,637
35	Ohio	$1,673
36	Nevada	$1,685
37	Connecticut	$1,713
38	Delaware	$1,715
39	Rhode Island	$1,719
40	Colorado	$1,751
40	Massachusetts	$1,751
42	Arizona	$1,769
43	New Mexico	$1,780
44	New Jersey	$1,797
45	Utah	$1,823
46	Maryland	$1,831
47	District of Columbia	$1,910
48	California	$1,994
49	Oregon	$2,062
50	Washington	$2,143
51	Alaska	$2,246

Health Care Cost Rankings[61] [62]

[61] Adapted From: "State Health Facts." Kaiser Family Foundation. 17 Aug. 2007 <http://www.statehealthfacts.org/>.
[62] 2005 Health Care Data.

Rank	State	Industrial Price (Cents per Kilowatt-Hour)
1	Kentucky	3.6
2	West Virginia	3.85
3	Idaho	3.91
4	Wyoming	3.99
5	Utah	4.24
6	Washington	4.27
7	North Dakota	4.32
8	Indiana	4.42
9	Nebraska	4.43
10	Virginia	4.46
11	Alabama	4.52
12	Missouri	4.54
13	South Carolina	4.55
14	Iowa	4.56
15	Illinois	4.61
16	Tennessee	4.73
17	Arkansas	4.74
18	Montana	4.83
18	Oregon	4.83
20	Kansas	4.85
21	South Dakota	4.95
22	Minnesota	5.02
23	North Carolina	5.04
24	Ohio	5.1
25	Oklahoma	5.11
26	Georgia	5.28
27	Michigan	5.32
28	Mississippi	5.37
29	Wisconsin	5.39
30	New Mexico	5.61
31	Colorado	5.74
32	Arizona	5.85
33	Delaware	6.21
34	Pennsylvania	6.29
35	Florida	6.46
36	Louisiana	6.71
37	Maryland	7.01
38	Texas	7.14
39	Maine	7.28
40	Nevada	7.71
41	Vermont	7.77
42	New York	8.23
43	Massachusetts	9.22
44	Alaska	9.29
45	Connecticut	9.4
46	California	9.55
47	New Jersey	9.76
48	Rhode Island	10.01
49	New Hampshire	11.48
50	District of Columbia	14.13
51	Hawaii	15.79

Energy Cost Rankings[63] [64]

[63] Adapted From: "Electric Power Annual 2006 - State Data Tables." Energy Information Administration. United States Department of Energy. 17 Aug. 2007 <http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html>.
[64] 2005 Energy Data.

Rank	State	Median Cost of Owner-Occupied Homes
1	Mississippi	$82,700
2	West Virginia	$84,400
3	Arkansas	$87,400
4	North Dakota	$88,600
5	Oklahoma	$89,100
6	Alabama	$97,500
7	Louisiana	$101,700
7	South Dakota	$101,700
9	Kentucky	$103,900
10	Texas	$106,000
11	Iowa	$106,600
12	Kansas	$107,800
13	South Carolina	$113,100
14	Nebraska	$113,200
15	Tennessee	$114,000
16	Indiana	$114,400
17	Missouri	$123,100
18	New Mexico	$125,500
19	North Carolina	$127,600
20	Ohio	$129,600
21	Montana	$131,600
22	Pennsylvania	$131,900
23	Idaho	$134,900
24	Wyoming	$135,000
25	Georgia	$147,500
26	Michigan	$149,300
27	Wisconsin	$152,600
28	Maine	$155,300
29	Utah	$167,200
30	Vermont	$173,400
31	Illinois	$183,900
32	Arizona	$185,400
33	Florida	$189,500
34	Alaska	$197,100
35	Minnesota	$198,800
36	Oregon	$201,200
37	Delaware	$203,800
38	Virginia	$212,300
39	Colorado	$223,300
40	Washington	$227,700
41	New Hampshire	$240,100
42	New York	$258,900
43	Connecticut	$271,500
44	Maryland	$280,200
45	Rhode Island	$281,300
46	Nevada	$283,400
47	New Jersey	$333,900
48	Massachusetts	$361,500
49	Hawaii	$453,600
50	California	$477,700

Cost of Living Rankings[65]

[65] Adapted From: 2005 American Community Survey, United States Census Bureau, October 2006.

Rank	State	Median Tax Rate
1	Nevada	0
1	South Dakota	0
1	Washington	0
1	Wyoming	0
5	Arkansas	3.75
6	Kansas	4
6	Mississippi	4
8	Colorado	4.63
9	North Dakota	4.8
10	South Carolina	5
10	Utah	5
12	Alaska	5.2
13	Hawaii	5.4
14	Florida	5.5
14	Kentucky	5.5
16	Georgia	6
16	Louisiana	6
16	Oklahoma	6
16	Virginia	6
20	New Mexico	6.2
21	Maine	6.215
22	Missouri	6.25
23	Alabama	6.5
23	Tennessee	6.5
25	Oregon	6.6
26	Nebraska	6.695
27	Montana	6.75
28	Ohio	6.8
29	North Carolina	6.9
30	Arizona	6.968
31	Maryland	7
32	Vermont	7.25
33	Illinois	7.3
34	Connecticut	7.5
34	New York	7.5
36	Idaho	7.6
37	Wisconsin	7.9
38	Indiana	8.5
38	New Hampshire	8.5
40	Delaware	8.7
41	West Virginia	8.75
42	California	8.84
43	Iowa	9
43	New Jersey	9
43	Rhode Island	9
46	Massachusetts	9.5
47	Minnesota	9.8
48	District Of Columbia	9.975
49	Pennsylvania	9.99

Tax Rate Rankings[66] [67]

[66] Adapted From: "Tax Rate Tables." 1 Jan. 2007. Federation of Tax Administrators. 17 Aug. 2007 <http://www.taxadmin.org/fta/rate/corp_inc.html>.

[67] Note: Michigan imposes a single business tax (sometimes described as a business activities tax or value added tax) of 1.9% on the sum of federal taxable income.

Rank	State	State Business Tax Climate Index
1	Wyoming	7.66
2	South Dakota	7.57
3	Alaska	7.23
4	Nevada	7.12
5	Florida	6.86
6	Texas	6.45
7	New Hampshire	6.21
8	Montana	6.2
9	Delaware	6.08
10	Oregon	6.04
11	Washington	5.95
12	Indiana	5.79
13	Virginia	5.68
14	Colorado	5.67
15	Missouri	5.65
16	Utah	5.63
17	Mississippi	5.57
18	Tennessee	5.49
19	Georgia	5.48
20	Alabama	5.47
21	Oklahoma	5.45
22	Pennsylvania	5.36
23	New Mexico	5.31
24	Hawaii	5.24
25	Illinois	5.23
26	South Carolina	5.22
27	Michigan	5.15
28	Arizona	5.14
29	Maryland	5.13
30	Louisiana	5.04
31	Kansas	5.04
32	Idaho	5.03
33	North Dakota	4.98
34	West Virginia	4.92
35	Arkansas	4.88
36	Massachusetts	4.88
37	Connecticut	4.83
38	Wisconsin	4.78
39	Kentucky	4.76
40	North Carolina	4.72
41	Minnesota	4.68
42	Maine	4.67
43	Iowa	4.56
44	Nebraska	4.53
45	California	4.51
46	Vermont	4.42
47	New York	4.16
48	District of Columbia	4.06
49	New Jersey	3.92
50	Ohio	3.82
51	Rhode Island	3.47

Tax Index Rankings[68]

[68] Adapted From: "2007 State Business Tax Climate Index." 2007 Background Paper. Tax Foundation. 17 Aug. 2007 <http://www.taxfoundation.org/files/bp52.pdf>.

Rank	State	% with Bachelor's or Higher Degree
1	District of Columbia	45.3
2	Massachusetts	36.9
3	Colorado	35.5
4	Connecticut	34.9
5	Maryland	34.5
6	New Jersey	34.2
7	Virginia	33.2
8	Vermont	32.5
9	New Hampshire	31.8
10	New York	31.3
11	Minnesota	30.7
12	Washington	30.1
13	California	29.5
14	Rhode Island	29.3
15	Illinois	29.2
16	Kansas	28.2
17	Utah	27.9
17	Hawaii	27.9
19	Oregon	27.7
20	Delaware	27.6
21	Nebraska	27.3
21	Alaska	27.3
23	Georgia	27.1
24	Montana	26.5
25	Pennsylvania	25.7
26	Maine	25.6
26	Arizona	25.6
28	North Dakota	25.5
29	North Carolina	25.1
29	Texas	25.1
29	Florida	25.1
29	New Mexico	25.1
33	Wisconsin	25
34	South Dakota	24.7
34	Michigan	24.7
36	Missouri	24
37	Iowa	23.8
38	Idaho	23.3
38	Ohio	23.3
40	Wyoming	23.2
41	South Carolina	23
42	Oklahoma	22.4
43	Tennessee	21.8
44	Alabama	21.4
45	Indiana	21.3
46	Nevada	20.6
46	Louisiana	20.6
48	Kentucky	19.3
49	Arkansas	18.9
50	Mississippi	18.7
51	West Virginia	16.9

Education Rankings[69] [70]

[69] Adapted From: National Center for Educational Statistics. 17 Aug. 2007 <http://nces.ed.gov/programs/digest/d06/tables/dt06_011.asp>.

[70] % of Population 25 Years Old and Over by Education Level – 2005 Data.

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