aVoilà: Optimizing and Evaluating Procurement Paths Across the Commercial Aviation Product Life Cycle

by

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division on May 11, 2012 in Partial Fulfillment of the requirements for the Degrees of Master of Business Administration and Master of Science in Engineering Systems

Abstract

Spirit AeroSystems is engaged in an unprecedented collaboration to supply a composite fuselage section for a new aircraft program. In most cases, Spirit cannot effectively leverage its composite sourcing experience with other customers due to differences in material and design. Management of Spirit's global supply chain represents a major opportunity by which cost savings can be achieved, particularly in the initial stages before investment recovery. This is augmented by the fact that engineering design changes are prevalent in early-ramp due to a concurrent emphasis on mass reduction. If a supplier cannot quickly and accurately adapt to design changes on critical-path parts, the resulting delays in production capability can cripple a program. As the aircraft ramps to full production, strategic points emerge when sourcing contracts can be re-negotiated or change/add parties.

This internship sought to identify, qualitatively and quantitatively through utility theory, the optimal sourcing targets for each part. It theorized that, at each stage of the product life cycle and dependent on each material classification (commodity vs metal type vs composite type), a trade-off exists between Total Landed Cost and risk elements that can be optimized. Based on the nature of the commercial aviation industry, critical risk elements were segregated logically between engineering (technological capability), performance (production and delivery), and global (financial and geopolitical) risk.

Efforts were then achieved through the design and development of a Decision Support System (DSS), titled aVoilà - a combination of the French 'avion' (aircraft) and 'voilà' (behold). Procurement teams are asked to work with suppliers to obtain metrics and survey data as model inputs, resulting in measures of utility for each risk element and cost. The DSS utilizes nonlinear programming to produce a sourcing mix (among up to 10 suppliers) with optimal utility. Finally, a methodology for data-driven continuous improvement of decision knowledge is outlined, incorporating risk-inclusive estimations of Total Cost of Ownership. Development primarily occurred within the framework of Spirit's French final assembly facility and its supply-base.

aVoilà was met with favorable response when presented to Supply Chain Management senior staff at Spirit headquarters in Wichita, KS. The prospect of improved standardization and control among supplier selection criteria is desirable. The model's ability to deliver scenario analysis could provide Spirit a baseline to negotiate with – asking a supplier to adjust contractual demands or invest in new technology in order to win business can be justified by a utility improvement.

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All of these folks exhibited a level of trust in my ability as an LGO student and former professional to roam the organization without micromanagement. This resulted in a truly immersive experience that tested my ability to consult internally, protect proprietary information, and foster relationships. I learned even more about the aerospace industry than I had anticipated, and I now feel better equipped for my post-LGO career challenges. It was extremely rewarding to see the first production unit arrive during the course of my research! For the opportunity to live and work in northwest France, and to have so much culture at my finger tips, I am forever grateful. The chance to travel to Sicily and the towns from which my ancestors emigrated in the early 1900s is also unforgettable. Thank you, Spirit.

It is also very important for me to call attention to my parents, who love and support me always and forever. I am their only child, so it has been difficult being far from them for so long – California, Arizona, Massachusetts, and now France – but those two voices on the phone can cheer me up on the gloomiest day, or make the best day better. My mother suffers from ailments, and is one of the bravest people I know. She constantly reminds me how proud she and my father are of anything I accomplish. I am thankful to them, for giving me the opportunity to do everything I aspire to.

This certainly extends to my late and living grandparents. Once again, I must defer to one of my grandfather's favorite sayings: "you don't say 'goodbye,' you say 'so long.'" Following graduation, and in the years that follow, this institute has given me a network of peers and faculty that I consider friends, and that I know I will meet again only to find them having the impact on this world to move mountains – to make it a better, more sustainable world. This includes my faculty advisors for this thesis, Don Rosenfield and Dan Whitney, who have done amazing things in their own working careers, for the Massachusetts Institute of Technology, and for the Leaders for Global Operations Program. I was fortunate to have their insights and to get to know them better as a result of this experience.

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1 Introduction

Spirit AeroSystems, one of the world's largest independent manufacturers of aerostructures, is engaged in an unprecedented collaboration with one of its customers to produce a composite fuselage section for an upcoming aircraft. This research took place at several Spirit locations, but was most heavily concentrated at Spirit France. The focus of the research was on risk mitigation strategies in supplier selection.

As the research direction refined throughout the internship, the frequency of concurrent engineering changes with initial stage production had a significant influence. In an effort to reduce aircraft mass while maintaining durability, Spirit and its customers drive changes, and production cannot always react proactively enough. The dynamics of engineering change are discussed in detail by Dawson (2011), but the concentration of this research is on the direct effect of those changes. Spirit's own suppliers, right down to suppliers of raw material, are often the first required to react to a design change. It is thereby critical that Spirit select its procurement strategy with a keen eye on the complexity of the material being sourced and the available experience with its manufacturing process. This becomes paramount in the early stages of the product life cycle. By the same token, this research theorizes that sourcing priorities (that is, the priorities by which Spirit selects from among a group of suppliers) may change dependent on the material classification and stage of the product life cycle. This prioritization occurs among four categories: Global Risk, Engineering Risk, Performance Risk, and Total Landed Cost.

If elements of risk and cost can be identified and gathered for each supplier under consideration, then a measure of the utility, or perceived satisfaction, associated with selecting that supplier can be ascertained, given the aforementioned priorities. This research served to identify those elements and the means by which to gather them, and then to develop a novel, standardized method of making the sourcing decision.

To this end, a general approach to the research was developed and followed (Figure 1). Following the presentation of background information on Spirit and the commercial aviation industry in Chapter 2, Chapter 3 details the material characterization and identification of risks that took place in the early months of the internship. With inputs in place, Chapter 4 explains the mathematical engine that drives the sourcing decision. Chapter 5 provides a look at the user-interface built to receive inputs and communicate with the mathematical engine. Finally, Chapter 6 details the practical use of the system, along with its continuous improvement through standardized feedback control. It also addresses the system's fungibility with other aircraft programs now and in the future.

Figure 1: General Approach

2 Company/Industry Overview

This chapter orients the reader to the company, industry, and program context in which this decision support endeavor occurred. It outlines several of the contributing forces that shaped the environment in which Sprit sources material and goods among a global customer- and supply-base.

2.1 Business Environment at Spirit

As one of the world's largest independent, first-tier aerostructures (structural airframe components) manufacturers, Spirit AeroSystems, Inc. (Spirit) is placed in a precarious situation: in order to diversify the customer base and hedge against failures among its product portfolio, Spirit must seek supply contracts from companies that are direct competitors. In the past, there was simply no need to manage numerous customer relationships.

Spirit was divested from Boeing Commercial Airplanes. The company was formed in 2005, when Canadian investment firm Onex Corporation acquired Boeing's Wichita and Oklahoma operations and renamed the new company Spirit AeroSystems. The Wichita division of Boeing traces back to 1927, and for much of its history produced military aircraft. However, the last several decades saw the division shift to commercial aircraft production for numerous Boeing products. As a result, the 2005 acquisition also resulted in Onex acquiring a great deal of commercial aircraft culture, manufacturing experience, and second-tier supplier relationships from Boeing (Spirit, 2011).

After acquiring the BAE Systems Aerostructures business unit facilities in Prestwick, Scotland, and Samlesbury, England, Spirit went public with a November 2006 IPO. Onex retains majority voting ownership. Embracing opportunity and the best interests of the shareholders, Spirit has aggressively pursued business ventures within its core competencies – fuselage, wing structures, pylon, and nacelle - among a host of new customers. The most notable among them is Airbus, a direct Boeing competitor in the commercial space, with which a large foundation of wing structures business came packaged with BAE. Boeing (83%) and Airbus (11%) contributed the largest proportions to Spirit's revenue for fiscal year 2010, which topped \$4.1B. The customer list also includes Sikorsky, Bombardier, Gulfstream, Rolls-Royce, and Mitsubishi, among others. A \$28.3B backlog in customer orders gives the company a firm foundation on which to build and grow (Spirit, 2011).

2.2 Move toward Large-Scale Integration and Composite Materials

Significant forces are at play in shaping the direction of the commercial airline industry toward light-weight, high-strength components. With global exports and imports trending upward, along with increased passenger travel, demand for aircraft has increased. Meanwhile, rising petroleum prices have been the primary factor leading to airline default due to the lack of a sustainable enterprise. The airline industry is highly price-competitive, and airlines are often unable to pass increasing fuel costs on to the customer. In addition, not all airlines have effectively hedged against rising oil prices, and there is fear that another sustained period in excess of \$90/barrel will bankrupt several (Jackovics, 2012). Spirit's customers depend on the health of the airlines for revenue, and have aggressively pursued the advanced use of light-weight, high-strength composite materials to achieve the type of fuel-reductions airlines crave. This has resulted in a considerable order backlog on upcoming composite aircraft offerings.

With new technology and efficient engineering at an all-time premium within this industry, Spirit's customers have moved toward an extended enterprise model of production, effectively serving as integrators for their latest offerings. Rather than developing significant portions of the aircraft in-house, companies reduce cost and mitigate risk by maintaining ownership within core competencies while sourcing major assemblies to first-tier suppliers like Spirit. Global sales reach is also enhanced by offset requirements stipulating that certain key countries contribute to the manufacturing of an aircraft if that country intends to purchase the aircraft. Further, suppliers are entrusted with detail engineering design responsibility. Spirit is responsible for major sections of the first offerings by its customers to consist primarily of light-weight advanced composite material (Spirit, 2011).

Over the life of any program, Spirit assumes and counts on a reduction in the cycle time (pertaining to capacity) and spend (pertaining to contract negotiation) per ship-set produced. Learning curves are generally used to dictate reductions in production schedules. An 85% learn rate, for example, would correspond to a 15% reduction in the expected cycle time for each doubling in the number of units produced. From a cost standpoint, goals set by management with some milestone ship-set counts will serve to incentivize progress. Spirit cautions that failure to reduce production costs as anticipated may result in decreasing margins for Spirit over the life of its products and the need to record a forward loss for the current contract accounting block (Spirit, 2011).

2.3 Supply Chain and Procurement Overview

2.3.1 Historical Challenges

The principal raw materials used in Spirit's manufacturing operations consist of the metals aluminum and titanium, along with advanced materials such as carbon fiber used to manufacture composites. Spirit also uses purchased products such as machined parts, sheet metal parts, non-metallic parts and assemblies, many of which are considered commodities. Some assemblies and subassemblies used in the final aerostructure assembly are directly purchased (Spirit, 2011).

As of this writing in 2012, Spirit has approximately 1,510 active suppliers with no one supplier accounting for more than 4% of cost of goods sold. The employed strategy is to seek long-term supply contracts with the largest suppliers to secure attractive pricing terms. Further risk mitigation is achieved in raw materials. Fixed or reduced rates governed by the existing high-volume raw material supply relationships of customers may be passed on to first-tier suppliers like Spirit, which protects against rate volatility (Spirit, 2011). Spirit's Supply Chain Management (SCM) organization prides itself on maintaining competitive material costs by continually seeking out cost reduction opportunities. This includes many global sourcing initiatives.

With their original equipment manufacturer (OEM) customers moving toward large-scale integration, first-tier suppliers like Spirit have gained greater flexibility to source freely. A number of risks are inherent to this increased freedom to source. For one, high switching costs substantially limit the ability to change supply strategy in a mature aircraft program (Spirit, 2011). In order for a first-tier supplier to change its own suppliers during the life of a program, copious testing and certification would be necessary – amounts that could hinder the production rate or ramp. Further, a movement of or re-investment in expensive capital equipment would follow. Thus, any move must be well-justified quantitatively and qualitatively, and such moves are complicated by orders of magnitude depending on the risk level associated with the type of material being sourced. A decision to change a commodity supplier, for example, is generally less difficult to execute than to procure a complex part previously produced in-house. Just as this hinders the ability to win new business from OEM customers outside of program onset, it trickles down to the second-tier supply-base and the flexibility with which first-tier suppliers can source.

2.3.2 Second-Tier Supply Base

The quality and delivery capability of the second-tier supply-base is also paramount. Regular deliveries of essential materials and purchased components are counted on, and in many cases sourced with limited options. If these suppliers are unable or refuse to deliver for any extended period of time, and alternate methods cannot be negotiated, the deliveries, revenues, and profits of the first-tier supplier may be impacted (Spirit, 2011).

Even with solid negotiations in place, supply chain risk extends down to the quality standards and delivery adherence of each supplier. Each OEM dictates technical specifications, and in an integrated environment where OEMs trust first-tier suppliers with engineering design, the first-tier supplier may augment these technology specifications with additional constraints. The failure of a contracted supplier to exhibit process capability based on 'design for manufacturing' can adversely affect production schedules. This makes initial supplier selection, contract terms, and switching costs critical.

Other supply risks include but are not limited to (Spirit, 2011):

• Destruction of suppliers' facilities or their distribution infrastructure

• Work stoppage or strike by suppliers' employees

• Failure of suppliers to provide materials of the requisite quality or in compliance with specifications

• Failure of essential equipment at suppliers' plants

• Failure of suppliers to satisfy U.S. and international import and export control laws

• Failure of suppliers to meet regulatory standards

• Failure, shortage or delays in the delivery of raw materials to suppliers

• Contractual amendments and disputes with suppliers

• Inability of suppliers to perform as a result of the weakened global economy

2.3.3 New Challenges

First-tier suppliers, like Spirit, will continue to be challenged going forward by an increasingly diverse customer and product portfolio. This necessitates the development of new facilities in new geographies, in addition to forming strong relationships with several companies that have distinct corporate cultures. These companies must engage in thorough site selection processes to determine where to build their factories and warehouses – considering not only cost minimization but also any strategic advantages, such as building in close proximity to a port when serving an overseas customer.

From a 'design for manufacturability' standpoint, there is complexity introduced by having a relationship with customers who are major competitors. OEMs often approach the overarching design requirements for their aircraft offerings in different ways, as a result of varying engineering philosophies and/or manufacturing capabilities. For example, if Spirit has previous experience producing composite fuselage sections for one customer, producing a similar section for another customer will not necessarily offer leveraging opportunities. The choice of materials and manufacturing processes may be considerably different.

2.4 Spirit France Functional Overview

In fall 2009, Spirit began construction on a new 60,000-square-foot facility in Saint-Nazaire, France. The site is considered part of a wholly-owned subsidiary of Spirit for French customs purposes and to fit within the tax structure. Saint-Nazaire is a harbor town on the right bank of the Loire River estuary, and Spirit France served as one of the primary research locations for this thesis. Among other reasons, Spirit was attracted by the region's expertise in composites (McMillin, 2011).

Enormous transportation cost savings dictated that Spirit set-up shop in Saint-Nazaire for final assembly of a composite fuselage section (McMillin, 2011), including the addition of flooring and window/door frames. At the point that it is transported to the customer, the structure will be approximately 65 feet long and weigh approximately 9,000 pounds. Later, it is transported to the OEM for final integration. Once integrated, the completed aircraft will fly to the consumer airline. Operations in Saint-Nazaire began in 2011, with the first line unit entering production during the course of research for this thesis.

A key challenge with having its own employees stationed in France is that Spirit must adjust to the staggered production schedule consistent with French holidays. The industry standard is to take most of August off as vacation, and many religious holidays mark the French calendar – four in May alone. Production plans and delivery schedules must be adjusted accordingly, and may result in higher inventory holding costs at times to mitigate risk (McMillin, 2011).

2.5 Chapter Summary

Spirit AeroSystems, one of the world's largest independent manufacturers of aerostructures, is engaged in an unprecedented collaboration to produce a composite fuselage section for a new aircraft program. This is one example of a current trend in the aerospace industry for first-tier suppliers to produce similar parts for multiple OEM customers. In many cases, first-tier suppliers cannot leverage their sourcing experience with other customers due to differences in material and design, particularly within newer technologies associated with composite manufacturing. The manner by which these companies manage their global supply chains represents a major opportunity by which cost savings per ship-set can be achieved, particularly in the initial stages before investment recovery has begun. This is augmented by the fact that engineering design changes are prevalent in early-ramp due to a concurrent emphasis on mass reduction. If a supplier cannot quickly and accurately adapt to design changes on critical-path parts, the resulting delays in production capability can cripple a program. As the aircraft ramps to full production, strategic points emerge when make/buy decisions can be re-evaluated and sourcing contracts can be re-negotiated or change/add parties.

3 Opportunity Identification

This chapter orients the reader to the factors which influenced the direction and research conducted in this internship. It discusses capabilities and constraints relevant to this internship in building a decision support methodology and tool for standardized sourcing strategy in commercial aerospace. The chapter will detail the first element of the general approach, material characterization, while introducing the risk factors relevant to the use of utility theory.

3.1 Supplier Selection Criteria – Current State

In the risk sharing collaborative model that the industry is moving toward, major aerospace suppliers like Spirit all work under the leadership of the OEM. The OEM serves the role of integrator, and facilitates communication between its suppliers to share information and coordinate the development of the aircraft. OEMs may discourage first-tier suppliers from direct collaboration with one another, preferring to serve as intermediary. One reason for this is to ensure suppliers stick to the schedule earnestly, without incorporating knowledge of delays elsewhere in the build. For example, the supplier for a forward fuselage section that is behind schedule is not intended to alleviate schedule pressure on the center and rear fuselage suppliers (Dawson, 2011).

Each individual first-tier supplier has varying degrees of freedom in choosing its own suppliers for raw material and detail parts. If the OEM chooses to dictate its own second-tier suppliers, there are typically two potential reasons. The first is simply an existing long-standing relationship for a certain material. The second is to help meet the complex offset requirements that the OEM must conform to in order to sell globally. This is aided by the fact that global sourcing at the second- and higher-tiers is rising rapidly as an acceptable option, especially within the commercial sector. For example, many international firms are technically as capable or superior to U.S. firms in the production of critical components, including ball screws, bearings, fasteners, forgings, aluminum, diesel engines, machine tools, ejection seats, and steel.

For the next 5-10 years, approximately two-thirds of the commercial aerospace market is forecast to be outside the United States, which will lead to increased emphasis on strategic work placement.

First-tier suppliers have a defined process in place for new item sourcing strategy. Generally, this includes (1) analyzing the procurement work statement, (2) categorizing the work package by commodity and part family, (3) gathering supplier performance data, (4) aligning sources with work packages, and (5) streamlining a list of potential suppliers. A defined contract negotiation process based on each supplier proposal follows. Supply Chain Management staff reviews cost comparisons and considers risk factors in making a selection. Metrics are available for mature suppliers, some of which are provided as an example in Figure 2.

Number of Major findings documented (System and/or Product) (Last 12 months)
Number of Parts Rejected by Customer
Second Effort Costs associated with rejections
Second Effort Costs / Total Value of Parts Received for the same period
Number of part disclosures (Notice of Escapements) written
Number of Supplier Initiated Rejections

Figure 2: Example of Supplier Risk Metrics

3.1.1 Vertical Integration - Make/Buy

There are two ways for a company to vertically integrate its supply chain. Companies that choose to move upstream and own more of the supply end of their value chain are said to be backward integrating. Those companies choosing to move downstream and own more of the customer end of the value chain are said to be forward integrating. A good vertical integration decision considers a number of factors. Beckman and Rosenfield (2008) identify four sets of factors that constitute a thorough vertical integration case: strategic factors, including whether or not an activity is critical to developing and/or sustaining the core capabilities of the firm; market factors, which focus on the dynamics of the industry; product, service, and technology factors, which relate those elements to operations; and economic factors, which balance the costs of owning an activity with the costs of transacting it instead.

In the case of Spirit, its 60 years of tool-fabrication experience can offer its customers state-of-the-art solutions that utilize the latest technologies, reducing tool counts and cycle time. A partial list of Spirit's capabilities includes tool design, CNC programming, machining, composite, aluminum and invar tooling, along with integration systems to support aerospace requirements (Spirit, 2011). Among those innovations are cutting-edge composite tooling technologies, a conduit to Spirit's composite aerostructure contracts. Spirit also offers integrated design-to-delivery production systems. With $3.29 Billion in Current Assets in 2011 and the majority of assets financed through equity (Spirit, 2011), Spirit is in an excellent position to backward integrate as a result of the aforementioned technical capabilities. Spirit can throw its own manufacturing capability into the sourcing decision analysis.

The decision to backward integrate must consider the aforementioned factors of strategy, market, technology, and economy. Meanwhile, forward integration is inherent to the first-tier supplier's design capability and the integrated model that directs OEMs to entrust their suppliers with design responsibility. In making a decision to vertically integrate a supply chain item, a company should ensure that the item lies within its core competencies, or that it may financially or technologically justify making an investment.

3.1.2 "Prove it to Move it"

A concept related to vertical integration, "Prove it to Move it" is a phrase to describe a sourcing methodology that can hedge against risk. If intolerable risks are present among the potential outside suppliers for a material or part, a company may choose to set up production of the item on its own shop floor. However, the intent here is not always to maintain ownership of that production. Rather, the company can continue to evaluate supplier readiness as the technology matures, sometimes even fostering a particular supplier along the way to ensure an easy offload. At the proper point in the item's life cycle, perhaps when capacity needs dictate, the now-'proven' technology is 'moved' to the desired supplier's shop, and the company may begin the process of clearing that capacity for alternative pursuits.

3.2 Dynamics of the Selection Criteria

In this section the reader is oriented to some of the dynamics that influence the selection process, whether by intent or indirect result.

3.2.1 Personnel – Integrated Teams

In researching critical success factors for strategic sourcing within the large-scale integration model, the importance of integrated input was identified. For materials exhibiting high incidence of engineering change, the technical expertise of engineering, stress, and research/development functions provide additional vantage points (and often counterpoints) relevant to the sourcing decision. Looking at a first-tier supplier through a political lens, it is not difficult to see disparity in the priorities different business groups might place on the sourcing decision. Stakeholders simply have different goals and underlying interests (Carroll, 2006) often brought about by the incentives placed upon them and also the pressures of their own work environment.

Supply chain staff, under cost pressure, might prioritize Total Landed Cost in a situation where an engineer may prioritize a supplier's technical competency. Further, an operations manager may deem quality and reliability of the supplier to be paramount. Without soliciting feedback from integrated teams prior to making the initial list of sourcing targets and discussing priorities, the best decisions are not always made. And that is not to say that supply chain managers should not be the ultimate decision-making body, only that standardized methodologies of incorporating priorities tolerable to all parties, and facilitating discussion, should be implemented whenever possible.

3.2.2 Ramp Stage

Beckman and Rosenfield (2008) describe the classic stages of the product life cycle. Products are introduced, go through a stage of rapid growth, mature, and then decline and often die. An additional stage, product development, is considered separate from introduction in this thesis as sourcing decisions made for the first few line units can present unique dynamics. Different types of products exhibit varying durations in each stage, and by no surprise commercial aircraft experience significantly long life cycles traditionally concentrated in the maturity phase.

Throughout the Product Development, Introduction and Growth phases, there is a much higher propensity of the aforementioned engineering design changes. In composite aircraft, this propensity is further enhanced by the constant pressure to implement weight reductions and increase fuel efficiency for the OEM customer. It is possible for the customer to implement a "wrenches-down" strategy, where design changes accumulate and are incorporated beginning with a certain ship-set count. However, it is also possible that the customer will expect changes to be implemented immediately, concurrent with initial-stage production. Both scenarios create complexity for the upstream suppliers associated with the design change, but the latter is decidedly more difficult, and can result in shipment delays and/or increased investment by the first-tier supplier. Thus, for technologies that historically exhibit a high incidence of engineering change, first-tier suppliers should source carefully and might emphasize a second-tier supplier's technical competency and flexibility rather than its Total Landed Cost.

3.3 Material Characterization and Sourcing Cluster

In this section the reader is given an overview of the types of materials prevalent in commercial aircraft production, grouped into three major buckets but also sub-divided into additional categories that may have significant influence over sourcing priorities. This was an independent analysis based upon industry research along with inputs solicited from industry engineers. Figure 3 presents a sourcing classification tree created for this thesis, where materials with highly complex manufacturing processes are depicted as deeply rooted to manufacturing capability and thereby more difficult to source. Stiffened composite skins (monolithic structures that require tremendous investment) are glaring examples of parts for which sufficient manufacturing complexity may warrant vertically integrated production. Along the horizontal axis, industry experience is similarly indicative of the number of sourcing options, in addition to the importance of a supplier's engineering and quality capability for newer technologies. These categories were loosely created for the purpose of this thesis, but in practice could correspond to a company's local material classification codes or other nomenclature.

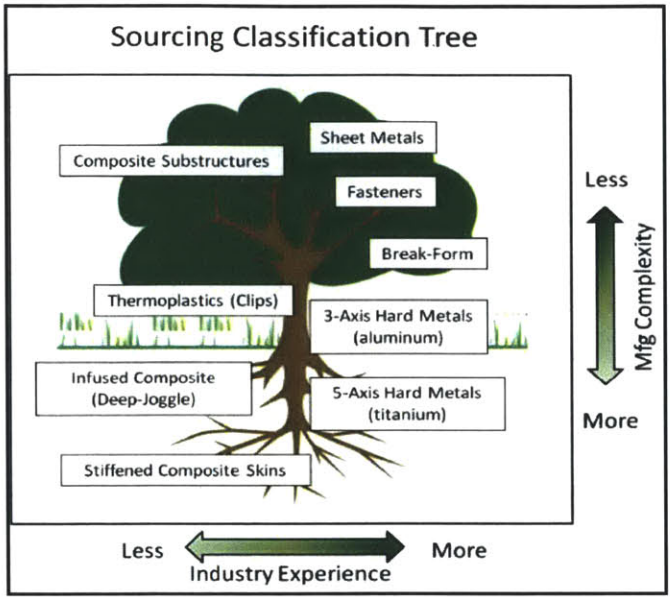

Figure 3: Sourcing Classification Tree

Major subcategories are distinguished by manufacturing complexity and industry experience. First-tier suppliers typically maintain a Bill of Materials (BOM) for the aerostructure, and each line item details a specific item being sourced. For the purposes of this thesis, an additional column is added to describe the item's material classification.

Further, because several line items may be identical or extremely similar, every item in the BOM was also placed in a 'sourcing cluster' – an identifier used in this research to ensure that multiple items are sourced together. The importance of the 'sourcing cluster' lies in ensuring the correct annual demand is used when calculating the landed cost of using a supplier.

3.3.1 Commodities

Commodity items consist of items purchased in larger quantities for multiple uses in the aircraft manufacturing process. This includes detail parts, sheet metal, and fasteners. These items are sourced in large quantities, and exhibit low-to-medium manufacturing complexity. Certain composites are essentially commodities; for example, frame clips may be manufactured as composite and utilized in large quantities. Clips and their associated structures can exhibit high manufacturing complexity (and material cost) depending on the design requirements being employed.

3.3.2 Metals

Aluminum, steel, and titanium are metals commonly used in commercial aircraft production. There are two types of titanium used, in general: commercially pure titanium, which is not as strong and is used where structural strength is not a major requirement, and titanium alloys which are used where structural strength is a major requirement. Titanium is an expensive and difficult metal to form, but it offers a desirable modulus of elasticity, making it superior to steel in many applications. The modulus of elasticity is an indication of how much the material will flex under load. If one material will flex more than another, then the more flexible material is less likely to crack over time. Aluminum is lightweight, durable, and easy to manufacture (as a result, it is less expensive than titanium). However, it is not as strong as titanium and exhibits different properties of conductivity and density. With the future churning toward composites and weight-reduction, titanium use should remain marginal going forward. It is likely to be used primarily when aluminum is not an option and where the savings over steel present a desirable trade-off. Although the industry experience in manufacturing these metal parts is substantial, the manufacturing complexity associated with production can range from simple (sheet metal) to highly complex (titanium). Complexity is also directly related to the number of axes (planes) the part requires.

3.3.3 Composites

Composite materials, such as carbon fiber reinforced polymers (and in many cases aluminum-lithium alloys, which have slightly different properties), are the primary means of weight reduction in the new generation of commercial aircraft. In spite of the weight reduction, composites remain highly durable and strong materials. Previous generations used the materials but never to the degree of today's offerings. The general manufacturing process for composite aerostructures entails strips or sheets of composite material layered on a precisely engineered metal tool and then cured in an autoclave, before being trimmed and drilled. Out-of-autoclave production methodologies also exist in this industry. Resin richness, fiber voids, and cracking are quality concerns.

There are also drawbacks to composite materials, starting with the maturity of the technology. Companies specializing in designing, manufacturing, and testing composite materials are constantly learning new lessons. This makes the sourcing decision for composite components critical, including vertical integration decisions. Because engineering changes are prevalent due to the relative immaturity of the technology and the desire to strip as much weight as possible from the aircraft, external sourcing for certain composite materials should prioritize the flexibility of the supplier to react quickly. First-tier suppliers with experience producing similar structures may gain additional foresight by leveraging their experience producing those similar products, and understanding what parts were the most prone to higher incidence of engineering change.

3.4 Components of Sourcing Criteria

As discussed, sourcing decisions are based upon Total Landed Cost and risk. Of course, there are numerous relevant risk factors and it is important to structure them in an intelligent way while minimizing complexity. Initially, global risk factors and performance risk factors were considered. However, as the importance of engineering change emerged in the early ramp for a composite aircraft program, a third set of factors, for engineering risk, were separated from performance risk. The theory being employed is that a dynamic tension exists between the three risk factors and the Total Landed Cost. This can almost be thought of as a 'tug-of-war' between the four elements, where balance is achieved by the most desirable combination at a given point in time. Desirability varies based on the material classification being sourced and the current stage in the product life cycle. This dynamic tension between Total Landed Cost and risk elements is displayed in Figure 4. For example, a composite clip during product introduction might employ sourcing priorities unique to a composite clip in a different life cycle phase, or to a 5-axis hard metal in the same life cycle phase.

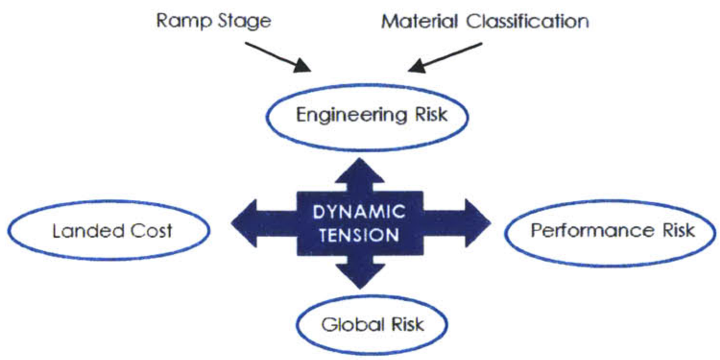

Figure 4: Dynamic Tension

Within this overarching structure, the specific constituents for each category needed to be defined. A number of methodologies were encountered for evaluating cost and risk among supply options, and it became apparent that no one method is vastly superior. Rather, the job of the organization is to put in place a system of decision support that best reflects the needs of their industry, and couple it with a periodic review and continuous improvement framework. The work of Feller (2008) was influential, presenting a comprehensive framework that was used by PerkinElmer, Inc, a provider of scientific instruments. Feller's list of unique risk factors was used as a starting point, and the majority of his measures and scoring scales are maintained. These risks span several categories: trade compliance, logistics, purchasing, finance, operations, quality, inventory, research and development, and sourcing.

From here, a focus group was utilized to alter the list to better reflect the concerns of the commercial aviation industry. The resulting 17 factors are distributed among the three risk categories. Each risk factor is scored on a 0-100 point scale to accommodate utility weighting in the decision support system. The risk scales may be linear, reverse linear, binary, or non-linear, dependent on the expected nature of the relationship between risk and the scoring metric. Estimations of the slope of these relationships (where applicable) come from the supply chain risk research of Feller (2008). These risk scales are subject to the interpretation of the supply chain experts in the organization and are easily altered in the model for each risk. This section will explain each risk and the rationale for the scoring system being employed. In all cases, a score of 0 signifies no perceived risk, and a score of 100 signifies extreme risk. It follows that a score of 100 has a negative impact on overall utility.

3.4.1 Global Risk

Global risk factors are those factors that are external to the operations of the company. They include financial, economic, and political risk.

- **Geopolitical -** Highlights the potential that doing business in another country may be impacted by political, economical or governmental instability, or social volatility. The measurement system being used is the AON score (AON), which provides free comprehensive country risk assessment. Figure 5 displays the scoring scale used to determine utility for Geopolitical risk. For example, a High AON rating yields maximal risk and receives a utility score of 100.

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
AON rating					Low	Low-Med	Med	Med-High	High

Figure 5: Geopolitical Utility Scoring Scale

- **Sales to First-Tier Supplier as a Percentage of Total Second-Tier Supplier Revenue –** Understanding the influence a first-tier supplier may have on its own supplier, based upon the proportion of that supplier's total revenue that it represents, can aid decision making. It is desirable for a supplier to have a diverse portfolio for financial stability in hard times, but too little influence can result in the de-prioritization of the first-tier supplier's work. Therefore, the 'sweet spot' of 20% of supplier revenue minimizes risk, while percentages below or above 20 increase risk (see Figure 6).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
Supplier Revenue (as % of Biz)	1	5	10	15	20	30	50	75	100

Figure 6: Supplier Revenue Utility Scoring Scale

- **Financial Strength -** To gauge the propensity of the company to default, an independent third party scoring system was sought out. There are multiple options, such as the Z-score, but for the purposes of this model, the FRISK score is utilized. The FRISK score uses a company's individual financial ratios and compares them to industry averages (FRISK Score). It is indicative of a company's probability of bankruptcy over a 12 month horizon. It is reported on a 1 to 10 scale, with a FRISK score of 10 indicating excellent financial strength and minimizing the utility score at 0 (Figure 7).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
FRISK Score					10	7.5	5	2.5	0

Figure 7: Financial Strength Utility Scoring Scale

- **Currency Volatility -** An assessment of the supplier's local currency is indicative of the economic conditions that supplier will operate under in contract negotiation. Here, a 5-year window is specified and the standard deviation over that period required (Figure 8). According to Simchi-Levi, Kaminsky, and Simchi-Levi (2008), currency fluctuations pose a significant risk in today's global operations. As a result, relative costs can change so drastically that manufacturing, storing, distributing, or selling in a particular region at a particular price can rapidly move from high profit to devastating loss.

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
5-year stdev					0.1	1	10	100	>100

Figure 8: Currency Volatility Utility Scoring Scale

- **Foreign Direct Investment -** A measurement of the investment being made in a country by external corporations. This is an interesting manner of taking into consideration the risk assessments of other corporations that have chosen to do business in the region. Feller (2008) utilized a survey conducted by AT Kearney (AT Kearney), which rated over 60 countries on a tier 1-4 scale, with a tier 4 representing poor investment potential and receiving a maximal utility score of 100 (Figure 9).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
FDI Scale					T1	T2	T3	T4	Other

Figure 9: FDI Utility Scoring Scale

- **International Trade Compliance -** This details the ability of the supplier to follow correct procedure in moving materials throughout a global supply chain. It is a problem that can make receiving in a standardized fashion a disaster, particularly when working with new or immature suppliers and during program onset. The score is determined using a survey (Appendix II), questioning if the supplier has import/export experience with the following factors:
    - Valuation of shipments
    - Use of commodity codes
    - Invoicing for international shipments
    - Marking of goods based on customer specifications

All factors are assigned an equivalent slice of the 100 utility points, and if any factor is not a present capability of the supplier it will contribute to the total score by that amount.

3.4.2 Performance Risk

Performance risk factors deal with the ability of the supplier to produce and deliver efficiently and effectively, and are within the supplier's control through investments in facility/capital/training/labor.

- **Capacity Utilization -** This is the estimated available capacity of the supplier. It is important that a supplier is not deeply under-utilized as it may signify financial instability due to unbalanced overhead and the inability of the supplier to win new business. However, some flexible capacity is desirable to assume short-term demand hikes or increases in product mix. 75% capacity utilization is set as the target level for minimal risk (see Figure 10).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
%	15	30	45	60	75	80	85	90	100

Figure 10: Capacity Utilization Utility Scoring Scale

- **Inventory Management -** Risk factors associated with inventory are surveyed. Each risk factor is worth a portion of the total score (see survey in Appendix II). The constituents include:
    - Are parts reworked locally, allowing for a 1-day turn?
    - Is inventory owned by Spirit, the supplier, or consigned?
    - When do warranty terms begin?
    - Are parts shipped individually or as an assembly?
- **Process Quality -** Indicators of a supplier's ability to deliver quality products. This is also accomplished through a survey, inquiring about the presence of the following quality methodologies (see Appendix II):
    - ISO Certification
    - ISO Compliance
    - Existence of specification documents
    - Corrective action plans
    - Formalized document control processes

- Inventory segmentation for defects

All quality methodologies are assigned an equivalent slice of the 100 utility points, and if any methodology is not a present capability of the supplier it will contribute to the total score by that amount.

- **Preferred Carrier -** Is the second-tier supplier capable of delivering/receiving using one of the first-tier supplier's preferred carriers? This is a binary scale, awarding 0 points if the supplier complies, and 100 otherwise.
- **Product Quality -** Based on a survey of factors for supplier performance that the supplier makes readily available. This is important in understanding the issues facing the supplier and building lasting supplier relationships. It allows a first-tier supplier to set high standards and expect its own suppliers to rise to meet them. This can be analogous to the supplier relationships built by Toyota and Honda. Honda, for instance, uses a report card to monitor its core suppliers, and sends the report to its suppliers' top management every month (Liker & Choi, 2004). The supplier is open with Honda, and Honda is providing constant feedback on their expectation of performance. It is important to note that novice suppliers or those dealing with new technologies may not yield well to an evaluation because it is difficult to determine what qualifies as good performance. However, a demonstration of tracking capability and open communication would be highlighted in these situations. An understanding of minimum acceptable standards and careful monitoring of early stage performance improvement would follow. Factors that constitute the risk score and should be included on this type of report include:
    - Defective parts per million (DPPM) or rejection rate tracking
    - Yield analysis
    - Delivery performance tracking
    - Part failure rates

All factors are assigned an equivalent slice of the 100 utility points, and if any factor is not a present capability of the supplier it will contribute to the total score by that amount.

3.4.3 Engineering Risk

Engineering risk is also within the supplier's control, but the focus here is on technological advancement and the organizational structure to support it. Engineering risk is a quality measure that is extremely critical in the early stages of the product life cycle, especially for composite aircraft. Certain technologies require an emphasis on these elements in the sourcing decision, or the risk of a supplier being unable to respond to a design change quickly or produce the specified part without capital investment can provide the remainder of the supply chain with numerous headaches. A first-tier supplier in the integrated environment is typically contractually obligated to make changes requested by the OEM customer, and also may be financially incentivized to propose changes through its own design team. Although including these factors within Performance Risk is possible and would reduce complexity, the segregation of this risk category was driven by the important and dynamic role of engineering design change in the commercial aviation industry.

- **Supplier Communication Capability -** This determines how easily the supplier can interact with Spirit based on communication ability, data management, order processing, and manufacturing plans. The supplier is surveyed for the presence of numerous factors (see Appendix II), including E-mail, Fax, CAD systems, order management systems, etc. The supplier is scored based on the number of such systems it possesses, with priority given to the systems Spirit deems most sensitive.
- **Average Year-Over-Year Growth -** Historical percent growth in supplier's revenue, averaged over a 5 year period. Slow growth is penalized, while rapid growth at or above 10% awards minimal risk (Figure 11).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
%					10	5	3	1	0

Figure 11: Average Year-Over-Year Growth Utility Scoring Scale

- **Years in Business -** Duration of firm's existence (Figure 12).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
# of years					10	7.5	5	2.5	1

Figure 12: Years in Business Utility Scoring Scale

- **Years of Experience with Material Class -** Duration that firm or its senior engineering team exhibits direct experience with the material/part being sourced (Figure 13).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
# of years					10	7.5	5	2.5	1

Figure 13: Years of Experience with Material Utility Scoring Scale

- **Fortune 500 Customers -** The number of large, successful firms that feel comfortable utilizing the supplier. The presence of even one other firm of such stature is meaningful (Figure 14).

	Scoring Scale								
	100	75	50	25	0	25	50	75	100
# of firms					>=1				0

Figure 14: Fortune 500 Customers Utility Scoring Scale

- **Supplier Organizational Competency -** Survey assessment (Appendix II) of the supplier's organizational structure, as it relates to engineering flexibility and fast, streamlined decision-making.
- **Supplier Sub-Tier Management -** Understanding how the second-tier supplier measures its own suppliers and the relationships it maintains is demonstrative of their ability to meet the first-tier supplier's demand needs. Point totals should be indicative of the relative value the first-tier supplier places on each element. Following the methodology of Feller (2008), four survey questions are asked for which a 'yes' answer produces a score of 0 (no risk), and a 'no' score produces the full weight:

- Does the supplier have a defined purchasing function to deal directly with its own suppliers?
    - Does the supplier have a defined quality engineering team to work through design issues with its suppliers?
    - Can the supplier demonstrate metrics it tracks for suppliers?
    - Are contingency plans present for minimal time delay in issue resolution?
- **Supplier Progressiveness -** Here, continuous improvement programs that are popular in industry and important to business practices are detected in a potential supplier. Again, the methodology of Feller (2008) is employed, with 'yes' answers receiving a score of 0 and 'no' answers receiving the full risk weight. Maximum point totals should be indicative of the relative value the first-tier supplier places on each element.
    - 6-sigma program
    - Lean manufacturing program
    - Safety program
    - 5S program
- **Research and Development -** This is a means of determining how capable the second-tier supplier is of collaboration with the associated first-tier supplier for development of new technologies or existing product improvement. A survey looks at three factors of equal weighting to determine a score:
    - # of historical customization projects
    - Dedicated R&D resources
    - New Product Integration (NPI) capability

3.4.4 Total Landed Cost

Total Landed Cost (from here on TLC) is the total cost of a product to a first-tier supplier up to and including its physical possession. It considers many factors beyond the obvious purchase price of the item. An accurate determination of TLC must account for transportation, duty, financing, inventory holding, investment, and engineering qualification needs. No model can account for every possible cost, some of which are specific to certain industries or locations. The compromise was to work with procurement cost analysts to determine the traditional factors encountered, and leave room for flexibility by allowing manual entry of unforeseen cost-bearing factors. This section will provide a walk-through of the cost factors considered and the methodology used in the calculation of TLC.

3.4.4.1 Transportation

Transportation costs per shipment boil down to a number of variables. Sheer freight can typically be the largest component, as many of the items being sourced are large and cumbersome. To calculate freight, the user must be aware of the approximate dimensions (cm) of the carton the item(s) being sourced will be placed in, in addition to the estimated weight (kg). When determining the rate of freight, most shippers compare the actual weight to a calculation of dimensional weight - a theoretical weight based on size. The greater of the actual weight and dimensional weight is the value used in the freight calculation.

For the purposes of this model, developed for Spirit France, a matrix was added that determines freight per carton based on weight and the zone for the country of origination. Two datasets are added to the model based on documentation of the preferred carrier's standard rates to France. First, a mapping of zone codes to the countries being sourced from. Second, a matrix of freight rates based on carton weight and zone code. These tables are used in conjunction via Excel's VLOOKUP function to import the correct freight rate into the model. Based on annual demand and the number of items per carton, the number of cartons required each year can be determined and multiplied by the freight rate to determine annual freight expenditure.

The user must also be aware of packaging cost per container, duties, customs clearance fees (fixed), fuel surcharges, hazmat, material handling, and harbor maintenance fees. Anything flying in by airplane is typically duty-free. The user must also understand what costs, by contract, the first-tier supplier will be responsible for. This contributes to the importance of what-if analyses. Finally, the user is asked to specify the expectation of expedite requirements (if applicable) and a multiplier to factor into the annual freight cost.

3.4.4.2 *Financial*

Feller (2008) presents an often overlooked element of cost (that is partially an opportunity cost) in considering the payment terms agreed upon by the first- and second-tier suppliers. Suppliers may offer discounts if payment is made within a predefined period. For example 2/10 Net 30 requires the invoice to paid within 30 days, and provides the manufacturer a 2% discount on material costs if the invoice is paid within 10 days. Net 30, Net 45, and Net 60 scenarios can be specified, and the associated impacts on Net Working Capital are calculated.

This works by looking at the most attractive terms from among the supplier options (the longest number of days required to pay), and comparing to the number of days required by each supplier. The difference in days is multiplied by the daily bank borrowing rate and total value of the cost invoice (material + packaging). This is the impact on Net Working Capital of paying the supplier more quickly. The model then compares this to the value of any discount provided by meeting the payment terms, and the difference provides the net impact on TLC.

3.4.4.3 *Purchasing*

Purchasing costs are the material costs of the items being sourced. This amounts to unit price multiplied by annual demand. Volume discounts must be incorporated manually be entering the adjusted (average) unit price.

3.4.4.4 *Inventory*

In a deterministic environment, inventory cost calculation is less cumbersome than in the stochastic environment (Silver, Pyke, & Peterson, 1998). Because customer demand and ramp rate is largely pre-determined, production needs are known far in advance and can be thoroughly planned. Thus, the number of completed aerostructures that need to be transported to meet customer commitments is known by each first-tier supplier, and that forecast is highly reliable within a defined time window.

It is based on a master schedule that controls all elements of manufacturing, reflecting flow time. It provides clear timing guidelines for planning, procurement, facilities, human resources, and airplane delivery. It is contingent upon three elements: process flow (including assembly sequence, labor hour estimates, and crew sizes), delivery quantities (yearly), and labor hours with established learning curves. The master schedule is subject to a firing order; simply, in line number order, tying a completed airplane to an end customer. This firing order permeates the major manufacturer's entire supply chain, right down to the supporting suppliers. Flow times for major subassemblies are offset to ensure arrival at final assembly in concordance. Buffers are created to allow for transportation, storage, and contingencies.

In such a deterministic environment, the uncertainties are lead time and yield. For the purposes of this thesis, the chosen method of dealing with these uncertainties is to assume for the worst possible results and order accordingly. This calls for an assumption of the longest possible lead time and the lowest possible yield. This method was selected due to the certainty of the demand and the lower volumes of material required in most cases. Non-detail parts should demonstrate a buffer stock in the event of scrap or rework needs, and assuming for worst-case is appropriate to avoid expensive delays. This method is similar to determining the thresholds for a min/max ordering system. Meanwhile, for detail parts that are repeatedly used throughout the aircraft, less aggressive calculation measures may be taken at the discretion of the user. This would require a probability distribution for lead time and/or yield.

The inventory needed to be robust to these uncertainties can be determined using the following variables:

D = Weekly Demand (units)

Tavg = Average Lead Time (weeks)

Tmax = Max Lead Time (weeks)

Ymin = Lower Bound Yield (units/week)

Yavg = Average Yield (units/week)

Inventory equations in the deterministic environment are as follows:

Order Point = (D * Tmax) + [(Yavg – Ymin) * Tmax]

Safety Stock = Order Point – (D * Tavg)

Process Stock = Tavg * D if pay on shipment

= 0 if pay on receipt

Because lot sizes are small, Internal WIP/Cycle Stock is ignored in this calculation.

To calculate inventory holding cost, Safety Stock and Process Stock are summed, and the result is multiplied by the company's inventory holding cost (expressed as an annual percentage). This gives a depiction of the average inventory present in the system, and the annual cost to hold that inventory.

3.4.4.5 Investment

All types of supply contracts may be proposed or agreed upon, and this aspect of TLC provides the most flexibility to the user in accurately representing proposals and engaging in hypothetical studies. User inputs are allocated for assistance fees, tooling contributions, and fixed charges that first-tier suppliers may incur due the development of their own suppliers. Although the intent was not explicit to model a vertical integration option, if the first-tier supplier can accurately assess the fixed and variable costs associated with overhead or construction of internal facilities, these fields may be utilized for comparison to second-tier supplier elections.

Finally, a first-tier supplier traditionally must invest the time of its own employees during an engineering qualification period. These costs may also be specified in the model, by estimating the staff size, required trips, and comprehensive daily cost of their labor and lost productivity. The cost of engineering qualification relates to the program phase, supplier technical capability, and supplier region of operation. Estimations should consider those elements.

3.5 Chapter Summary

First-tier suppliers, like Spirit, can pursue a number of channels and strategies when sourcing parts throughout a global supply chain. When choosing a method and strategy, the technical and material characteristics of the item being sourced and the state (ramp phase) of the aircraft program play important roles. This research theorizes that, dependent on the aforementioned factors, a different prioritization schema exists between risk elements and Total Landed Cost. The proposed standardized methodology began with the identification of the 17 risk factors most pertinent to the commercial aviation industry, segregated among global, performance, and engineering risk buckets. Unique means of determining a risk score, on a 0 – 100 point scale, were determined for each in order to facilitate utility calculation and nonlinear optimization, as discussed in forthcoming chapters.

4 Utility Theory and Mathematical Programming in Supplier Selection

This chapter will introduce the reader to the utility theory being employed to holistically evaluate up to 10 suppliers, quantitatively and qualitatively. Utility theory provides a methodological framework for evaluating among choices. The word 'utility' refers to the satisfaction that each choice provides to the decision maker. Thus, utility theory assumes that any decision is made on the basis of the utility maximization principle, according to which the optimal choice is that which provides the decision maker with maximal satisfaction (Keeny & Raiffa, 1976).

The chapter will then focus on the ability to apply mathematical programming as a means of optimizing the risk/cost utility based upon priorities and yielding maximal satisfaction. This approach was taken because of the large dataset and structure of the model. In allowing a user to enter up to 10 suppliers, and accounting for the ability to multi-source while constrained by capacity and demand requirements, mathematical programming is a logical choice to reduce computation time. Solver is an easily utilized tool via Microsoft Excel, commonly available to most employees in large corporations.

4.1 Weighing and Diversifying Risk

With risk factors in place and risk scoring systems with equivalent scales (0-100 points) available for each, a standardized method of prioritizing the risk factors was introduced. The application of this risk prioritization strategy at Spirit is described in this section. Keeping in mind the importance of input from integrated teams, a range of Spirit employees, primarily stationed at Spirit France, completed a survey. This survey segregates the different materials/technologies found in the sourcing risk tree (Figure 3 in Chapter 3) into three categories: New Technology, Mature Technology, and Commodity.

For each category, the surveyor is asked to assess the priorities between Global Risk, Engineering Risk, Performance Risk, and Total Landed Cost throughout the 5 phases of the commercial aviation product life cycle. The surveyors were given a brief overview/training on the information being requested of them prior to completing the survey, to ensure adequate understanding. Representation of multiple business groups was achieved; however, it is recommended that, in addition, Wichita/North Carolina personnel with further strategic influence be consulted in the future.

The users were not asked to use a specific scale; rather, a geometric mean was taken from the available responses indicative of the central tendency among the set of values. The geometric mean achieves this by evaluating the nth root of the product of a set of n values. The major request was that the scores within a life cycle phase remain relative to one another. In the below example (Figure 15), which displays sample responses from a survey, the changing priorities as each material classification moves through the product life cycle are depicted. Larger values indicate higher priority. Relative ship-set counts are also listed, based on the historical ramp and decline of a retired aircraft program but these numbers are largely superfluous and should be ignored, as different aircraft exhibit varying demand profiles.

New Technology	Life Cycle Phase				
	Product Development	Introduction	Growth	Maturity	Decline
	1-10	10-50	50-500	500-1500	1500+
Global Risk	3	2	2	1	1
Engineering Risk	4	4	3	3	2
Performance Risk	2	3	4	4	4
Total Landed Cost	1	1	1	2	3

Mature Technology	Life Cycle Phase				
	Product Development	Introduction	Growth	Maturity	Decline
	1-10	10-50	50-500	500-1500	1500+
Global Risk	3	3	3	2	2
Engineering Risk	1	1	1	1	1
Performance Risk	4	4	4	4	3
Total Landed Cost	2	2	2	3	4

Commodity	Life Cycle Phase				
	Product Development	Introduction	Growth	Maturity	Decline
	1-10	10-50	50-500	500-1500	1500+
Global Risk	3	3	3	3	3
Engineering Risk	1	1	1	1	1
Performance Risk	2	2	2	2	2
Total Landed Cost	4	4	4	4	4

Figure 15: Example of Sourcing Priorities

A second critical input to the model is the priority of each of the 17 risks in the portfolio, within each category. This was accomplished through the application of a Failure Modes and Effects Analysis (FMEA). The chosen participants varied by risk factor. Global Risk was surveyed using supply chain management personnel, Engineering Risk included Engineering and R&D personnel, and Performance Risk included the opinions of all parties. Gathering opinions in this manner was deliberate such that the individuals with the highest level of expertise were providing the critical inputs.

The FMEA process requested each interviewer to score the risk factors for the potential severity to the organization, the likelihood of occurrence, and the risk detection mechanisms already in place within Spirit. Feller (2008) presents a scoring system where Severity is measured on a scale of 1 to 7 (7 having the most impact), Occurrence on a scale of 1 to 5 (5 being very likely to occur), and Detection on a scale of 1 to 5 (5 being difficult to detect). For each risk factor, the three scores are multiplied: Risk Priority = Severity * Occurrence * Detection.

Imagining the overall utility of the sourcing decision as a pie chart, each of the four elements of dynamic tension (Global Risk, Engineering Risk, Performance Risk, and Total Landed Cost) initially received 25% of the total utility. Within that 25%, the sub-risks receive weightings based on the relative Risk Priority Score within that category. For example, the Risk Priority Score for Geopolitical Risk was normalized among all of the other Risk Priority Scores within the Global Risk category, and then assigned the appropriate portion of the 25% chunk.

The resulting structure in Figure 16 depicts the 17 risks and the initial weights based on relative Risk Priority Scores (using sample data). Note that each of the four categories sum to 25% of the overall utility. The final step is to apply the categorical priorities generated based on material classification and ramp stage. Again, these priorities can take any scale, and Excel functions were used to recalibrate the weights for each of the 17 risk factors to reflect those priorities. For example, Supplier Revenue (an element of Global Risk) has a standard weight of 3.37%, but after applying a priority of 3 (out of 10) the standard weight for Global Risk rises to 30%, and Supplier Revenue follows by rising proportionally to 4.04%.

Category		Risk	Standard Weight (%)	Priority	Recalibrated Weights(%)
Global Risk	1	Geopolitical	5.29		6.34
	2	Supplier Revenue (% of Business)	3.37		4.04
	3	Financial Strength	4.60		5.52
	4	Currency Volatility	3.84		4.61
	5	FDI Investment	1.37		1.64
	6	International Trade Compliance	6.53		7.84
		Subtotal	**25.00**	3	**30.00**
Engineering Risk	7	Supplier Technical Capability	5.23		2.09
	8	Supplier Experience	4.57		1.83
	9	Supplier Organizational Competency	4.52		1.81
	10	Supplier Sub-Tier SCM	3.69		1.48
	11	Supplier Progressiveness	2.92		1.17
	12	Research & Development	4.08		1.63
		Subtotal	**25.00**	1	**10.00**
Performance Risk	13	Capacity Utilization	4.54		7.26
	14	Inventory Management	4.53		7.25
	15	Process Quality	2.48		3.97
	16	Preferred Carrier	8.76		14.02
	17	Product Quality	4.69		7.51
		Subtotal	**25.00**	4	**40.00**
Total Landed Cost			**25.00**	2	**20.00**
		Total	**100.00**		**100.00**

Figure 16: Risk Weighting and Recalibration

The recalibrated weights for each risk factor are applied to the score it receives (0-100) based on the respective risk scale. If Supplier A's Capacity Utilization receives a score of 25 out of 100, indicating low risk, it will receive 25% of its respective risk weight. In the example in Figure 18, it will receive a score of 25% * 7.26, or 1.82. In general, the computation is:

$$\text{Risk Factor Utility} = \text{Recalibrated Weight} * (\text{Risk Factor Score}/100)$$

4.2 Variables

When all of the risk factor utilities in a given category are summed, the result is the total utility for that category. Total Landed Cost is the only outlier, as its utility is based upon the supplier's cost performance relative to the lowest TLC among competing suppliers in the model. TLC scoring is linear, but it is set in such a way that the highest cost supplier receives a maximal cost utility ($0 receives a minimal cost utility), setting the utility scale. An alternative methodology is to have the user set the minimal/maximal utility thresholds for TLC, but this was not utilized in the current model. These input variables will be called $u_{i,j}$ where i represents supplier i (i = 1 to 10) and j = total utility score for category j (j = 1 to 4, representing each risk category and TLC).

The decision variables for the model come in two forms: whether or not a supplier is selected for sourcing (binary variables denoted s_i) and what percentage of the material being sourced will come from each supplier (variables bound between 0 and 1 and denoted p_i). The user may specify the maximum number of sources and minimum percentage of demand sourced from any one supplier, which act as bounding constraints, in addition to non-negativity.

Capacity also plays an important role as a constraint. p_i, the percentage of demand allocated to each supplier, must exceed the minimum percentage set by the user (m). It also must not exceed the capacity that the supplier is willing to allocate to Spirit (c_i). Further, the sum of all the capacity allocations among the suppliers must equal the annual demand (D) for the item being sourced. Through intelligent modeling, quotas based on import restriction from certain countries can be modeled by capping available capacity or adding additional constraints.

4.3 Objective Function

The objective is to minimize the value of a utility (U) function, as lower utility values signify less risk or cost pressure. Each category of risk and TLC contributes to the total utility by an amount determined by its own utility function (F). In its most general form, the mathematical program takes on the following objective function:

$$min\ U(F_1, F_2, F_3, F_4)$$

For the purposes of this model, a basic (and trivial) objective function takes an additive approach - with each utility function characterized by a linear combination of the percentage sourced from each supplier and the sum of the respective utilities for the four categories:

$$min\ U = F_1 + F_2 + F_3 + F_4$$

Engineering Risk: $F_1 = \sum_{i=1}^{10} p_i u_{1,i}$

Global Risk: $F_2 = \sum_{i=1}^{10} p_i u_{2,i}$

Performance Risk: $F_3 = \sum_{i=1}^{10} p_i u_{3,i}$

Total Landed Cost: $F_4 = \sum_{i=1}^{10} p_i u_{4,i}$

subject to

$\sum s_i \leq \text{max \# of sources}$	The number of suppliers selected must be less than or equal to the maximum # of suppliers specified
$p_i \geq m \; \forall i$	The percentage of demand sourced from any one supplier must exceed the specified threshold
$p_i D \leq c_i \forall i$	The demand allocated to each supplier must not exceed that supplier's available capacity
$s_i \in \{0,1\} \; \forall i$	Restricts supplier selection variables to binary
$0 \leq p_i \leq 1 \; \forall i$	Restricts percentage sourced from a supplier between 0 and 1
$\sum p_i = 1$	The sum of percentages sourced must total to 1 (for 100% demand allocation)
$p_i \leq s_i \; \forall i$	The percentage sourced from a supplier must be less than or equal to the sourcing decision variable (this ensures that if a supplier is not chosen, it will not be allocated demand)

When solved, this mixed integer optimization provides the decision maker with an optimal mix of suppliers to meet the demand requirements while maximizing utility (although, in this case, that is accomplished through a minimization). The current model employs the trivial linear objective and utility determination. This is trivial because it can be reached through heuristic – maximizing demand allocated to the supplier with the most desirable utility, allocating as much remaining demand as possible to the supplier with the second most desirable utility, and so on until all demand has been allocated. The greater benefit of mathematical optimization is realized when general utility functions are introduced. Arguments in favor of TLC and Performance Risk utilities being linear combinations of the selected supplier portfolio are sound but debatable; however, Engineering and Global Risk almost always experience significant mitigation effects when the portfolio of suppliers is intelligently diversified.

The extent of any mitigation effect must be determined by the management team, in addition to capping the maximal number of sources. This can be accomplished by altering the structure of the utility functions for Engineering (F_1) and Global (F_2) Risk. Total Engineering Risk utility, for example, may take the minimal Engineering Risk utility value among the supplier's in the portfolio selected, provided that supplier be allocated a specified minimal percentage of the total demand and demonstrate excess capacity in the event of a co-supplier defaulting. A similar example would have the overall Global Risk utility taking the value of a linear combination of the minimal 60% of the supplier portfolio, provided that it does not exceed a specified risk threshold. Again, these examples serve to incorporate into the model additional positive effects of diversification, which may also include synergies.

4.4 Chapter Summary

A standardized approach, incorporating cross-functional opinion, to determining weights for risk constituents reflects the broader goals of the organization. Based upon technology and ramp stage, the defined dynamic tension between TLC and risk categories results in measures of utility. These measures can be optimized via heuristic or mathematical program, to determine the most desirable sourcing strategy. While minimizing a linear combination of risk/cost and sourcing mix is effective, the objective can take on different formats based upon the preferences of the organization. It may be felt that there are increasing returns from a multi-source that begin to diminish at some point. Finally, this approach is very flexible in that elements of risk and variables/structure in the optimization may easily be altered within a model to reflect any continuous improvement efforts.

5 Decision Support System - aVoilà

A fun exercise in developing a system is its beautification. Considering the work location at Spirit France and the aviation industry in which this work took place, the chosen name for this system is aVoilà – a combination of the French 'avion' for 'airplane' and 'violà' for 'behold.' The chosen interface is Microsoft Excel (best viewed in the version for year 2007). The system utilizes built-in Excel functions, Visual Basic programming, buttons/macros, dynamic charts, and Solver all within a self-contained Excel file. The file is easily copied or transferred, resulting in a tool for the analysis of hypothetical supplier mix and contract structure scenarios that may be placed side-by-side.

5.1 Welcome Screen

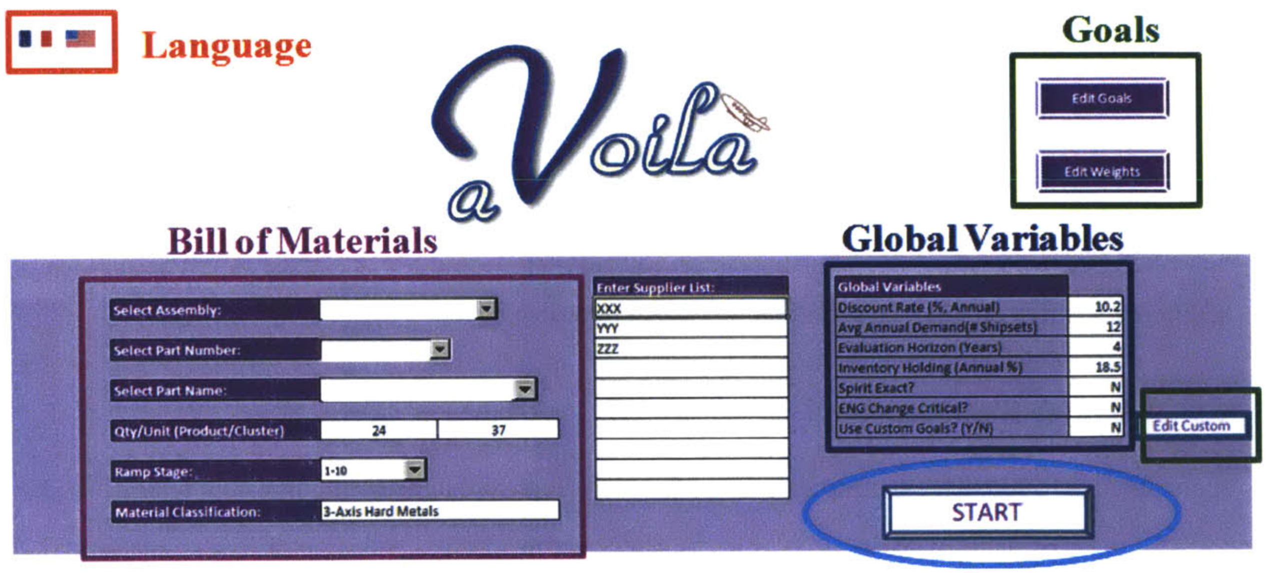

Figure 17: DSS Welcome Screen

The main screen from which the user can set the global model inputs and navigate is presented in Figure 17, and populated with sample data. Because the tool was developed for the French site, the language may be toggled (red box). The user may also edit the goals and weights that were detailed in preceding chapters, if updated FMEA analyses change these elements (green box). In the event that a material classification is deemed by the user to not perfectly fit one of the preselected categories (new technology, mature technology, or commodity), custom goals may be selected. Goals may take any relative scale, as the model will recalibrate through normalization. Up to 10 supplier names may also be input here, each of which will require a full risk and cost evaluation survey.

The purple box utilizes a series of Excel list box forms to connect the Welcome Screen to the product's Bill of Materials (BOM). The user may select either the part number or name, grouped by major assembly, and the system will determine the material classification and quantity per ship-set for the item being sourced. The quantity is not based upon line item but the aforementioned sourcing cluster, which groups all similar line items for logical co-sourcing from the same supplier group. The user must also enter the ramp stage (or life cycle phase; based on cumulative ship-set counts) for which the sourcing decision will apply.

The material classification and ramp stage combine to determine the utility goals that will be used in the mathematical optimization. All interactions are specified using Visual Basic programming and lookup functions from a BOM connected to the worksheet. It is recommended that the BOM be maintained and updated with frequent recurrence in development through introduction and at least quarterly thereafter.

The blue box displays the global variables vital to the model (all values have been changed to protect confidential information). These inputs are used to determine annual demand, net present value for TLC (the user must specify a discount rate and up to a five-year valuation horizon), and whether the sourced material is expected to exhibit high incidence of engineering change requirements or, in the case of Spirit, Spirit Exact dimensional tolerances. The presence of either or both design complexities serves to enhance the priority of the Engineering Risk category, with an emphasis in the early stages of product ramp and a sharp drop in effect at maturity.

Once all inputs have been set and the user is satisfied, the 'start' button (light blue circle) can be clicked to enter the risk input worksheets.

5.2 Risk Factor Inputs

In the preceding chapter, the FMEA analysis and risk recalibration methodology was outlined. Figure 18 serves to recount the manner by which this is achieved. Priorities are determined based on the material classification and ramp stage, with additional priority placed on Engineering Risk in the presence of heavy change incidence or dimensional tolerance requirements (shown in Figure 18 as 'Spirit Exact' in the case of Spirit). Category weights are then recalibrated based on these priorities through normalization, and all associated risk factor weights follow suit.

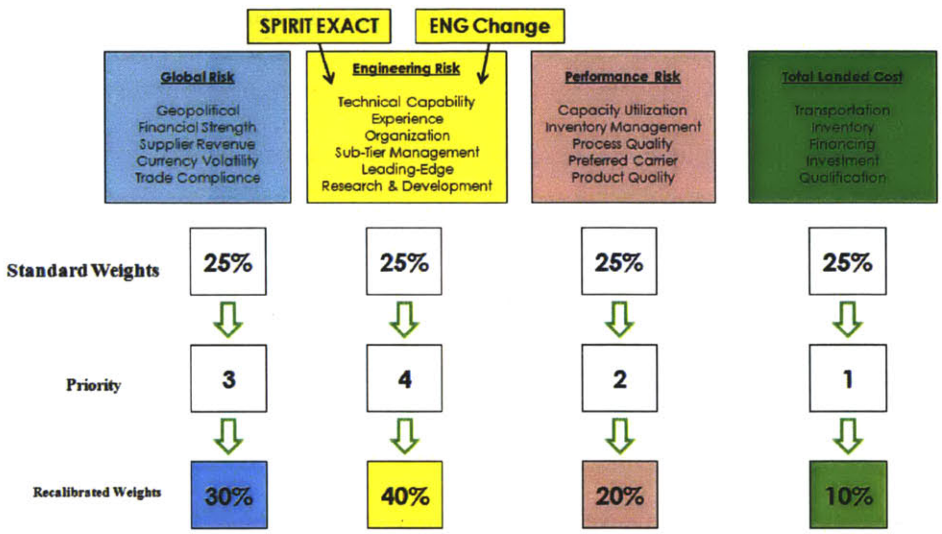

Figure 18: Weight Recalibration

Figure 19 depicts the Global Risk input sheet. Here, each individual risk element that constitutes Global Risk is present, along with the units of measurement and recalibrated weight. Each risk follows the scoring convention detailed in section 2.4. If the decision maker has satisfactorily gathered all inputs from the risk/cost assessment survey (Appendix II), it is straight-forward to enter values for each supplier into the associated yellow box (many of which restrict entry values with dropdown lists). Once a value is entered, logical functions are used to determine the associated score (0-100). If the scale is numerical, scores are interpolated linearly when falling between the fixed denominations. That value is then multiplied as a percentage by the risk factor weight to determine the contribution of that risk to the Global Risk utility.

For example, the Geopolitical Risk for Supplier XXX, based upon AON rating, is Medium-Low. This correlates to a risk score of 25 (of 100). The risk factor weight for Geopolitical Risk is 6.34, so its final contribution to utility is 6.34 * 25% = **1.6**. Although each risk factor may have a different scoring scale, the logical functions are differentiated accordingly and the calculation methodology for utility contribution is identical. For Supplier XXX, the total Global Risk utility after scoring all risk factors is 6.9 out of a possible 30 contribution points. This implies that Global Risk has relative importance to the sourcing decision, and Supplier XXX scores well in this category. Supplier YYY fares worse at 12.4 out of 30.

aVoila

TLC	ENG Risk
Perf Risk	Analyze

			Scoring Scale									1		2	
Global Risk Worksheet	Units	Weight	100	75	50	25	0	25	50	75	100	XXX	Score	YYY	Score
Geopolitical	AON Rating	6.34					Low	Med-	Med	Med-	High	Med-Low	25.0	Med-Low	25.0
													1.6		1.6
Supplier Revenue (% of Business)	%	4.04	1	5	10	15	20	30	50	75	100	40	37.5	50	50.0
													1.5		2.0
Financial Strength	FRISK score	5.52					10	7.5	5	2.5	0	8	20.0	5	50.0
													1.1		2.8
Currency Volatility	5-year stdev	4.61					0.1	1	10	100	>100	4	33.3	25	54.2
													1.5		2.5
FDI Investment	FDI scale	1.64					T1	T2	T3	T4	THER	T2	25.0	T4	75.0
													0.4		1.2
International Trade Compliance	Survey	7.84					0	25	50	75	100	10	10.0	30	30.0
													0.8		2.4
GLOBAL RISK SCORE		30.00											6.9		12.4

Figure 19: Global Risk Worksheet

This methodology is repeated for Engineering and Performance Risk factors, and screenshots of these entry forms can be found in Appendix I. The buttons in the upper-left corner allow for navigation between the worksheets, with the 'Analyze' button a final step directing the user to the optimization.

5.3 Total Landed Cost Inputs

Total Landed Cost (Figure 20) is also compiled via a survey of the supplier's operation. All of the relevant elements, as discussed section 3.4, must be gathered by the surveyor and input into the model for each supplier evaluated. This includes:

- Supplier location and shipment destination
- Average and maximum lead times
- Carton dimension and cost
- Expedite estimation
- Duty, customs, fuel, hazmat, etc. estimations
- Financial terms contracted
- Average and lower bound yield for inventory owner (typically supplier) during lead time
- Assistance and tooling fees, including estimates for engineering qualification visits

Global Risk | ENG Risk | Perf Risk | Optimize

Total Landed Cost Worksheet	1 XXX	2 YYY	3 ZZZ
Annual Demand (units):	444	444	444
Order Frequency (weeks):	5	5	5
Unit Price (€)	55.00 €	70.00 €	44.00 €
Unit Weight (kg)	5	5	5
Location			
Country/Region of Origin (FG):	Afrique du Sud	Israel	Etats-Unis
Ship To Location:	SNZ	SNZ	SNZ
Transportation			
Shipping Method:	Air	Air	Ocean
Average Lead Time (weeks):	2	3	4
MAX Lead Time (weeks):	4	4.5	5.5
Units/Carton:	5	5	5
Packaging Cost/Carton (€):	150.00 €	150.00 €	150.00 €
Carton Height (cm):	60	60	60
Carton Length (cm):	80	80	80
Carton Width (cm):	60	60	60

Figure 20: Portion of TLC Worksheet

5.4 Mixed Integer Linear Optimization

Upon completing all risk and TLC components, the decision maker is now capable of utilizing the mixed integer program embedded in the DSS (Figure 21). This optimization utilizes Microsoft Excel Solver and all objective and constraint functions are already embedded – the user need only click the 'Optimize' button (green box). The purple boxes represent user-input constraints – the maximum number of sources and the minimum percentage of demand that can be allocated to a single source. It may be the case that the user desires a sole source, which implies 100% of the allocation. However, the selection in Figure 21 denotes that up to three suppliers may be selected, but no one supplier should be responsible for less than 20% of the demand allocation.

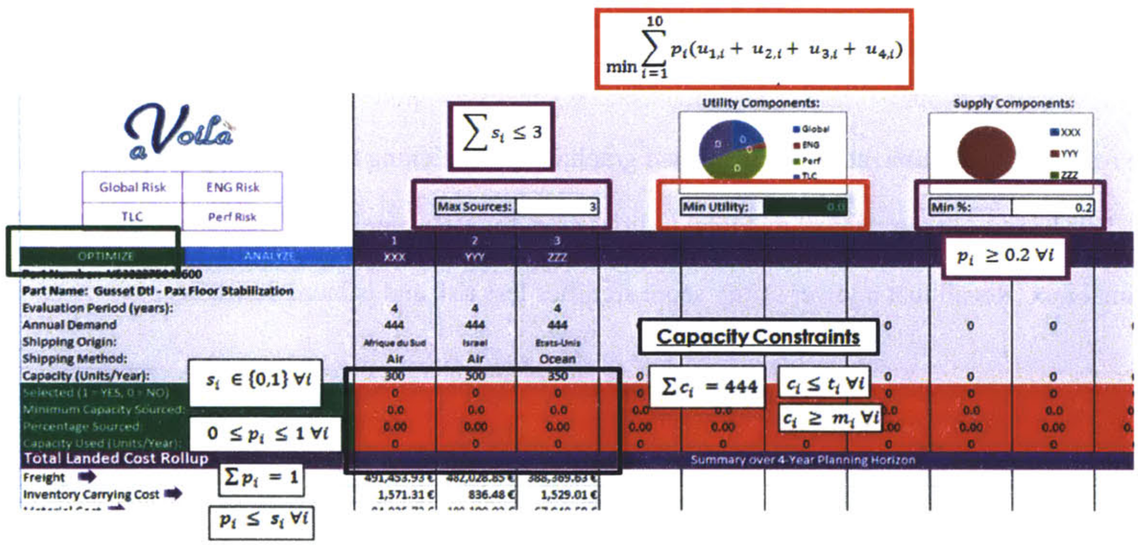

Figure 21: Mixed Integer LP with Equations

With all input parameters and constraints in place, the model works by altering the decision variables (black box) until an optimal (minimal) utility score is converged upon. This implies the lowest risk/cost trade-off based upon sourcing priorities. In Figure 22, the results of one such optimization are reported. Here, Supplier XXX and Supplier ZZZ are selected, with XXX supplying 68% of the material while utilizing its full capacity. Supplier ZZZ supplies 32% of the material, while retaining burst capacity in the event of a sudden need, perhaps due to a shortfall by XXX.

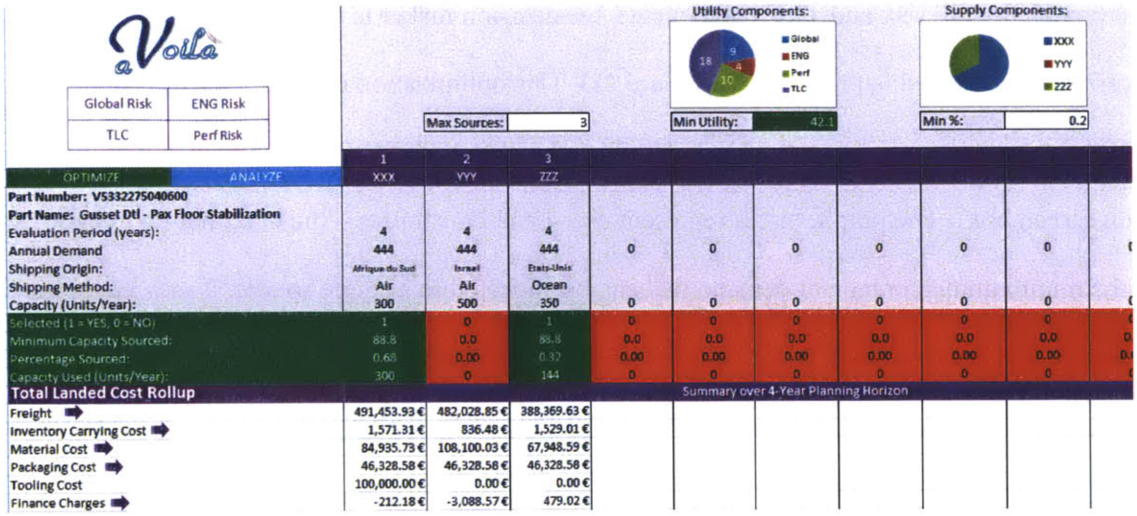

Figure 22: Example of Solved Mixed Integer LP

5.5 Roll-Up and Charts

The results of the optimization are displayed graphically by clicking the blue 'Analyze' button (see Figure 23). This breaks out the relative and total utility scores for each supplier and compares them to the optimal mix. Recall that a lower utility score signifies less risk and is more desirable.

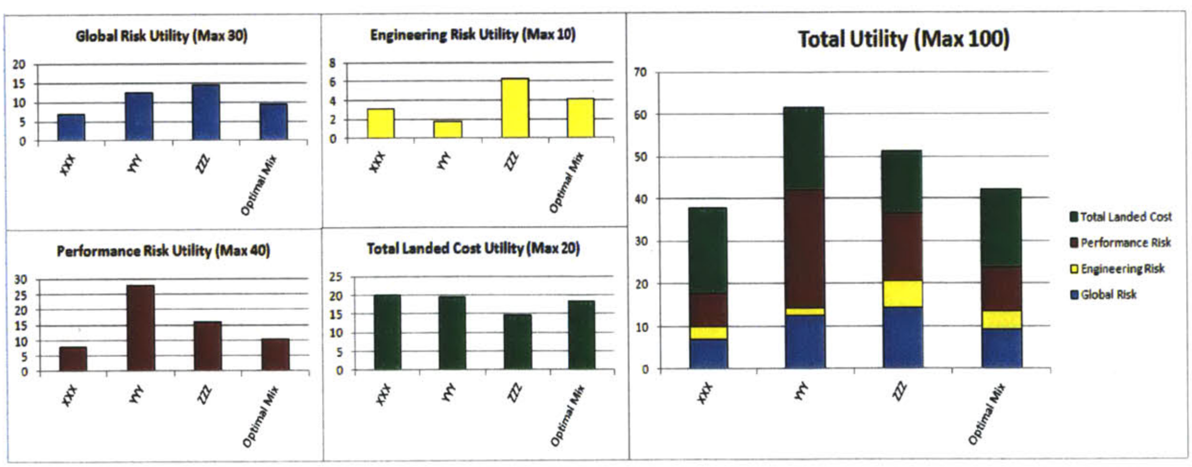

Figure 23: Graphical Representation of Utility

In addition, the model calculates a Total Cost of Ownership (TCO) for each supplier. According to Moser, most companies make sourcing decisions based on price alone, resulting in a 20 to 30 percent miscalculation of actual off shoring costs. Moser provides a TCO estimator that functions by estimating the effects of various risks on Total Landed Cost. The method selected to baseline TCO is to match risk elements to TLC components they most logically impact. For example, Performance Risk will most directly affect freight, inventory, and packaging cost. Meanwhile, Engineering Risk will most directly affect material and tooling. The final risk utilities for the optimal supplier mix are appended to the related TLC components, to determine TCO. The amounts appended are also displayed graphically, an example of which may be seen in Figure 24. Although this calculation is crude, it serves to provide an important baseline that carries forward to the discussion of feedback control response in Chapter 6.

An important element of TCO within the context of commercial aircraft manufacturing is the idea of travelled work. Common to the commercial aviation industry, and prevalent in the face of engineering delays, travelled work is defined as any parts and processes that must travel with the aircraft or aircraft sections because incorporation at the intended site was impossible due to time delays. The primary culprit in many cases is part availability. For example, if a second-tier supplier experiences a delay in shipping a non-critical part, the first-tier supplier may still be able to complete the aerostructure and send it on to the OEM customer. However, once the delayed part finally arrives at the OEM's facility, the first-tier supplier will have to send personnel to the OEM's factory floor to complete the work that would have taken place earlier and in a different location.

The total cost of doing this is difficult to estimate, but it includes factors such as labor, rework delay, airfare/hotel for travelling employees, and expedite cost. It requires companies to earmark managers whose sole duty is to manage the travelled work manufacturing process. Because Engineering Risk is intimately tied to this, and most directly so in the early stages of the life cycle, the effect of Engineering Risk contributes to TCO by a higher factor in early ramp.

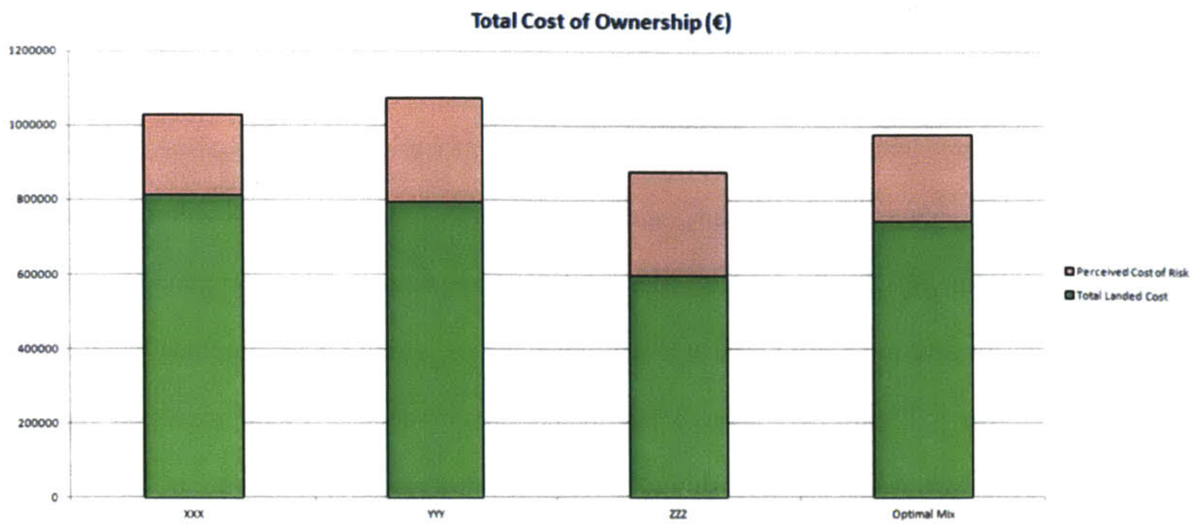

Figure 24: Total Cost of Ownership Estimate

5.6 Scope of Usage

aViolà is a nimble decision support system that allows the user flexibility to add and remove risk constituents, edit weights and use custom goals, alter constraints/objective functions, and input unique cost variables. It is for this reason that the scope of usage can expand beyond selection from among a group of external suppliers. Although an independent analysis might preclude the use of aViolà, once potential site locations are narrowed, a vertical integration decision to produce internally at a new or existing facility can effectively be modeled. Farrell (2006) points out additional cost variables that should be considered in such a decision, such as tax structure on transfer price, real estate, and infrastructure. Although hefty, these increased costs can be accounted for by the minimized risk of doing business with an external supplier, should a clear competency advantage be exhibited. It can also highlight the importance of co-location to some transportation/logistics cost intensive operations, involving extremely heavy assemblies.

The scope of use is further bolstered by the ability to look at several estimations of the same supplier side-by-side to determine the optimal contract structure. Up to ten profiles for the same supplier may be compared at one time for utility optimization. By placing all elements of the contract that may be negotiable on the table and engaging in scenario analysis, the supply selection decision can be approached in layers: first, optimize the contract proposal for each candidate; next, select the optimal candidate(s). This approach provides novel standards for the negotiation process.

An inherent risk to the level of flexibility offered by the tool is that different users may perceive and utilize it differently, and may even attempt to game the system by offering colorful methods that paint the picture they desire. The responsibility lies within a strong management team to maintain standardized methods for cost and risk analysis in unique scenarios, and make any necessary changes consistent with the feedback control loop discussed in Chapter 6.

5.7 Chapter Summary

aViolà is a user-friendly decision support system designed entirely within Microsoft Excel. There is flexibility built into the tool in order to keep most scenario analyses within the range of possibility, should the user be creative enough. However, strong management must ensure that the flexibility offered is not abused and that unbiased standards are followed. Further, with dedicated programming resources behind it, continuous improvement of the application through a structured feedback control system (discussed in the forthcoming chapter) should be considered a necessity.

6 Recommendations

This chapter will highlight the recommended actions Spirit and/or other companies in similar supply positions might take moving forward. The design and development of this system spanned the research duration, with proliferation in the early stages. While implementation was not achieved at Spirit, an outline for how it might be achieved is provided here.

6.1 Ownerships

With a global customer- and supply-base, management of different products takes place at multiple Spirit facilities. The ability to benchmark and share best practices may be limited at times by geography and intellectual property among competing customers. This means that a system might be piloted for one program/product, but if that direction did not channel through corporate (that is, ownership was maintained at the program level), than a breakthrough system might never realize its full potential – other aircraft programs at Spirit may not have the opportunity to implement and develop it to suit their needs.

The global supply chain management (SCM) organization, based out of corporate headquarters in Wichita, Kansas, is the organization responsible for setting the sourcing strategy. With the diversification of Spirit's contracted aerostructure business units likely to continue, it seems logical that the implementation of a standardized DSS should come from strong ownership within SCM that possesses a broad influence among business units. This is also the most obvious manner of getting the dedicated support of automation to continuously improve the system.

In order to build early confidence in the tool, it is suggested that the system be used to revisit past decisions to see if the choices made match the system output. Deviations could be checked against opportunities for improvement or successes actually experienced by the program relating to that sourcing decision. If the system highlights problems for which prior knowledge would have improved the decision process, then organizational confidence will follow.

6.1.1 Responsibility and Scope

Fortunately, Spirit SCM in Wichita responded favorably to the program when a consultative presentation was provided at the conclusion of the internship. It is worth noting that, while many of the inputs to the model were pieced together through FMEA and survey, the parties providing input were often too rooted in European sourcing. The inputs to this model need to be reconsidered to achieve an organizational strategy, and not a local one. Placed in the hands of a global supply chain manager, the FMEA feedback can be driven through the most experienced and influential individuals at Spirit.

In addition, more robust material classification codes, category weights, and risk factor weights would be the initial need for the SCM owner. From there, the intricacies of working with certain customers can be considered. For example, customers manage their production runs and simultaneous development phases differently. At the corporate level, and working with representatives from each program, the vantage point is high enough that Spirit employees can detect these differences and adjust risk factors accordingly. Also consider that, if each aircraft program were permitted to adjust factors with complete independence, a departure from standardization and a waste of organizational knowledge and best practice would result. This is the reason it is recommended that changes be driven through a corporate owner that solicits the input of program personnel.

The users, on the other hand, should range from supply chain directors making critical decisions to cost analysts gathering the inputs and engaging in sensitivity analysis on contract structure (what changes a supplier would need to make in order to justify its selection). These are bargaining chips that, once proven with repeated use, could become a standard that suppliers value and use as a driver for investment in risk mitigation for their own businesses. Further, an up-front approach to what the model values and how the supplier can achieve it can help to foster strategic, long-lasting relationships. This is especially valuable in the higher context Western European supply base.

One caveat here is that the information shared with suppliers should be treated with care. There is always a possibility that suppliers will attempt to game the system if they are well-aware of the factors receiving the highest priority. In addition to verifying their capabilities through site visits, Spirit should closely monitor recent financial transactions by the supplier and require open lines of communication.

6.1.2 Documentation

The primary means of documentation comes from within the graduate thesis and also within the DSS itself. In addition to a user-friendly interface, all of the Visual Basic functions within the user forms and modules of the program have been thoroughly commented to provide an automation owner with each sub-procedure and the reason for its inclusion. If the direction were to import the system to a web-based interface, these resources would provide the developer with the specifications needed to do so.

6.2 Feedback Control for Decision Criteria

The proposed model is theoretical in nature, and highly unproven. For this reason, it is absolutely critical that a good feedback control mechanism be in place to monitor the process and map results to positive change. Kempf (2002) describes a process (Figure 27) that revolves around five core ideas: "1) For decision performance to be improved, something must be measured. 2) For the measurements to be meaningful, decision policy execution must be consistent. 3) For execution to be consistent, the policy must be thoroughly discussed, agreed, and clearly documented. 4) Consistent execution of the policy and measurement of the results will lead to ideas for improvement that must be tested and incorporated. 5) Over time, goals will change necessitating changes in measurement and method."

6.2.1 Performance Evaluation

A logical method of capturing a measurement of sourcing strategy is to monitor the use of a company's management reserve fund. The management reserve is the amount allocated by a company in order to compensate for risk. Although any amount allocated was not disclosed by Spirit, the demands placed upon such a fund over time would highlight the effect of various risk factors on Total Cost of Ownership, in addition to fostering a recalibration of risk weights with some frequency and the potential addition of new risk constituents. Examples of costs allocated to this fund might include disaster relief to facilities, expedite shipments beyond normal expectations, additional investment in supplier tooling, and recurrent, unplanned engineering qualification of the supplier.

As a first-tier supplier to a number of OEMs, Spirit ultimately has to decide how best to utilize its knowledge-base of other products to this end. However, if a new product exhibiting similar characteristics to a mature product were to anticipate a parallel use of a management reserve fund, improved mitigation strategies can be incorporated into the new product's risk priorities.

6.2.2 Continuous Improvement

As Kempf (2002) decrees, continuous improvement over time is critically important for future competitiveness. If Spirit believes in the use of a standardized system to baseline supplier selection, it must use that system in a consistent manner to yield meaningful results. This means that a decision tree should be identified and followed with the iteration of a sourcing decision. Latitude for an override (deviation from the choice suggested by the DSS) should be given in the decision tree, but there should be a defined reason for doing so, such as an existing supplier relationship, customer mandate, or offset credit requirement. Those reasons for deviation should be documented. Under normal circumstances, following the decision tree should yield a supplier selection, and over time the use of the management reserve to deal with problems relating to that supplier should be scrutinized.

Individuals will be more willing to buy-in to using a system if they know that there will be a periodic review and a forum to suggest positive changes, which can be implemented for the next contract iteration by a qualified system owner. Changes, however, should not be blindly executed: a change control process (Figure 25) is needed to separate the strong suggestions from the weak ones, and that involves integrated teams. The belief is that the involvement of integrated teams in all phases of the sourcing decision and improvement effort will facilitate better communication and fewer blind-spots during the sensitive design and introduction phase of a program.

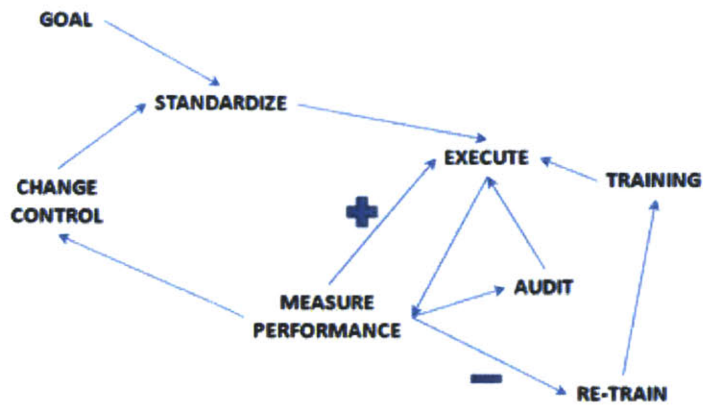

Figure 25: General Change Control Process

6.3 Review of Supplier Interactions

Early in the internship, opportunities were afforded to interact with and visit first- and second-tier suppliers within Spirit's European network. Because they occurred early on, they did not serve to validate the decision parameters, which had not yet been determined. Rather, they provided valuable research on the characteristics of the suppliers, and any of their limitations that could have potential impact on Spirit's ability to deliver the associated aerostructure. The visits sparked internal discussion around risk constituents and aided in the creation of an evaluation survey that can be quickly completed for a given supplier for entry into the DSS. They also provide examples of supplier selections that would have been good candidates for aViolà's structured selection process, even if the results had proven identical. What follows is a description of the suppliers and their relationships to Spirit. Key procurement contacts were made and maintained within each organization, and a mock survey for aViolà was filled for Supplier F to gauge ease of assessment, with satisfactory results at a one-day turn while having the dedicated support of a Supplier F procurement representative.

6.3.1 Supplier D

Supplier D is a designer and manufacturer of composite parts and sub-assemblies. The company currently operates with most of its business in aerospace, and the remainder within other industries such as sports and leisure. The company touts the ability to deliver on all phases of the product life cycle, from raw material selection through integration and serial production. Based on this expertise, Spirit contracted the company for production of an unprecedented composite component.

Supplier D has been in business since the early 1980s and exports just under half of its production. Within its production facilities, all of which are located in France, the company has dedicated research and development resources. The company touts clean rooms for composite lay-up, polymerization and machining areas, serial production/assembly, and quality control stations. The company also provides its customers with detailed performance metrics. It was not difficult to assess their organizational competency, with representatives assigned directly to each customer and progressive programs including Lean manufacturing and 5S factory organization. Supplier D is ISO-9000 certified and supplies for a number of large companies. With all these qualities considered, Supplier D performs fairly well in a high-level assessment of Global, Engineering, and Procurement risk category utilities. The Engineering Risk category is paramount, because the 'step' (that is, bend or curve in the composite part) required of Supplier D is among the most complex in any portion of the aerostructure.

Although assessments were unable to be undertaken, primary competitors capable of designing this part include Supplier E. Supplier E is a company that is arguably more robust in the production process, sporting superior tooling. Supplier D's process is more manual, although similar quality issues may still have been predicted. The apparent driver for Supplier D's victory in gaining Spirit's business was significant cost reduction over the nearest competitor and a prior relationship with Spirit's customer. At the time of this writing, Supplier D has requested an increase in Spirit's contracted investment due to new tooling requirements based on engineering changes to the design. This raises costs into the range of Supplier E's original quote, and the superior tooling of Supplier E may not have called for such additional investment.

6.3.2 Supplier F

Supplier F, similarly offers complete services to its customers, from the design phase to the manufacturing of aeronautical subassemblies. It specializes in both composite and hard metals, with many automated machining tools on multiple axes. The company has been in existence since the late 1980s, and over the last decade has attained ISO certification and implemented lean manufacturing. The company produces parts for most of the major aerospace OEMs. Supplier F boasts a dedicated technical service organization and vigorous inspection standards that are available to the customer.

Supplier F was an interesting case study as the internship duration presented the opportunity for a site visit to both the Supplier F headquarters and the operations of a second-tier supplier, Supplier G, which supplies 'widgets' to Supplier F. Supplier F uses these widgets in the construction of a larger subassembly to be sent to Spirit. Supplier F also provides the same subassembly for another section of the aircraft, produced by a different tier-1 supplier, akin to Spirit. Supplier F was originally not intended to be a supplier to Spirit, but when the supplier originally intended to produce the subassembly was unable to meet transportation cost targets, Spirit opted to vertically integrate the assembly aspect and procure the similar components from Supplier F. Site visits from Spirit procurement personnel were ongoing to ensure dock date commitments were met. The parts procured are made of titanium and aluminum-lithium, which are mature technologies. Supplier F also adds pilot holes placed with rigorous tolerance to meet dimensional requirements. Due to the volume of different customers' products competing for space and a lack of visual control, opportunities for improvement were noted.

As a brief aside, the site visits were also eye-opening to the subtleties of working within other cultures, which US-based first-tier suppliers will likely do on an increasing basis going forward, For example, the Western European culture, much like the Chinese culture, is of a higher context: value is placed upon the ability to build relationships. As Platt (1994) states, "working in France has to do with *honneur*." As a result, a stronger relationship with supplier personnel was noted to be an asset in getting the job done more efficiently and effectively, as compared to weaker relationships within a domestic supply chain.

In cases where dates were slipping on Supplier F's end, root cause was traced to its own suppliers, among them Supplier G. Supplier G is located in a city in the southwestern region of Europe, and has a job shop environment, which may raise questions of scalability in a production ramp. The company boasts short lead times with expedites possible, but thus far has not provided tracking numbers to monitor package locations. The aforementioned engineering change issues truly took precedence at the second-tier supplier level, where it was evident that some parts were slated for scrap because revised design diagrams no longer supported the initial parts that were machined.

The breakdown of organizational structure and systems while moving closer to the raw material in the supply chain is remarkable. Womack and Jones (1996) note in their recollection of Toyota, "[second- and third-tier suppliers], accounting for more than two-fifths of the total manufacturing cost of the vehicle, are outside the Toyota Group's reach and most have been resistant to Toyota's requests to streamline their thinking." It raises the question of how much influence the customer should attempt to exert at each level in its own supply chain given the design volatility of the part being sourced.

6.4 Fungibility within Spirit

Clearly, fungibility, or mutual substitution, is an important element at play for a model that is designed for a global corporation supporting many customers, suppliers, products, and environments. Although the tool was developed amidst European sourcing, consideration was given throughout to making the tool nimble to Spirit's diverse needs. Items such as technology types, category weights, risk constituents, risk factors weights, and utility scales are easily altered. For this reason, the thought process is that a mature system could contain additional global variables specifying the customer and product being sourced, and this would be associated with a unique 'profile' agreed upon by the business groups staffed for that product. This means that the unique weights and factors agreed upon would automatically be imported into the model upon the selection of that customer-product profile, prior to stepping through the model.

6.4.1 New Technology Dynamics

One of the more interesting aerospace trends and a key driver for this work is the increased utilization of composite materials in the latest commercial offerings from Spirit's customers. It follows that most composite technology within the aircraft is relatively new, and this model regards it as such. However, in 5-10 years the landscape may change drastically, with new denominations of composite taking precedence or new structural compounds entirely. Thus, the flexibility of the system to map material classification codes to a profile of manufacturing complexity and industry experience is desirable, and should be periodically reviewed.

6.4.2 Synergies with Business Objectives

By the same token, new customers also exhibit important differences in design and manufacturing strategy that the user must take into account when prioritizing risk. An entirely new operating and business culture has to be accustomed to, and over time additional differences will be detected and can be reacted to for the most favorable sourcing decisions. This supports Spirit's ability to diversify its portfolio of customers, and also to achieve future design wins from mature customers.

6.5 Future Opportunities

Future opportunities related to this research include an exploration of the offset requirements that influence sourcing decisions at both the customer and first-tier level. While the proposed model looks to optimize sourcing for an individual line item on a product bill of materials, a more global optimization of the entire bill of materials that places constraints on sourcing location to meet offset targets would represent a great potential research project.

Within this research, it should be noted that a more thorough investigation of the resources Spirit currently has in place should be conducted. Risk tracking was encountered; however, that data may be underutilized or irrelevant. Further, an exploration of the extent to which Spirit can rely on its own tribal knowledge across customer boundaries was difficult to ascertain. Wall, Anselmo, and Flottau (2010) note that a key challenge of the new risk sharing collaborations is "figuring out how to operate with new partners while still protecting core customer relationships and technical competencies."

Further exploration of objective functions within the mixed integer program is also a worthy activity, as there are various schools of thought on the risk mitigation properties of multi-sourcing and the objective function might also vary based upon the material classification and ramp stage. Finally, although a high-level implementation strategy has been identified, the lean implementation of a standardized process is not always trivial in an organization sporting well-tenured staff with a set way of doing things. This system would represent a departure from the norm, and while top management support is absolutely needed, an intelligent rollout and training protocol will also have to be developed by the owner, including a test environment and perhaps the aforementioned analysis of past sourcing decisions.

6.6 Chapter Summary

Moving forward, if this model is to have a future it is critical that Spirit define ownership within SCM and automation to drive a baseline of priority and risk weights through the most knowledgeable integrated teams in the organization. A pilot phase can follow, logically with sourcing decisions for upcoming product variants and current contract expirations. A rollout to other programs can follow, which should consider the unique priorities of that customer and product. To close the loop, a close monitoring of unforeseen costs incurred, based on sourcing decisions that were made, should enable a change control board to determine and implement system refinements.

Although implementation was not achieved in the research duration, this type of standardization in the selection approach should continue to be pursued as a means to reduce TCO over the life of each commercial aircraft program. Some sourcing decisions have not been beneficial to Spirit, and in the presence of a standardized process of justifying those decisions, it becomes possible to determine the root causes and improve the decision-making process.

7 Conclusion

Spirit enters a critical period in its existence – poised to continue diversifying its customer and product portfolio. This is a key to remaining competitive and continuing to win contracts for major aerostructures. This research opportunity offered insight into the dynamics at play which may create delays in program infancy. The engineering and manufacturing dynamics of the customer dictate the pressure placed upon Spirit that permeates Spirit's own supply chain. This prioritizes the sourcing, vertical integration, and supplier development decisions Spirit makes in order to maintain a flexible and responsive supply chain that meets the needs of each customer as quickly as possible.

aViolà was developed for the purpose of aiding the sourcing decision and putting in place novel standards of risk assessment. The ability to subjectively measure risk and Total Landed Cost, while quantifying the qualitative aspects, can provide first-tier suppliers like Spirit with a baseline for the decisions they make that can be looked back upon for continuous improvement opportunities. A system of this type can assist commercial aviation sourcing experts in an industry recently affected by delays due to technological readiness factors and the weight-reducing demands of the consumer airlines. A pilot program would represent a victory, but adoption by the greater SCM organization and proliferation among technologies/customers would yield the knowledge-gains and garner the interest to make standardized sourcing an expectation within commercial aviation.

Appendix I: Category Worksheets (with Sample Data)

Global Risk:

TLC	ENG Risk																
Perf Risk	Analyze																
			Scoring Scale									1		2		3	
Global Risk Worksheet	Units	Weight	100	75	50	25	0	25	50	75	100	XXX	Score	YYY	Score	ZZZ	Score
Geopolitical	AON Rating	6.34					Low	Med-	Med	Med-	High	Med-Low	25.0	Med-Low	25.0	Low	0.0
													1.6		1.6		0.0
Supplier Revenue (% of Business)	%	4.04	1	5	10	15	20	30	50	75	100	40	37.5	50	50.0	60	60.0
													1.5		2.0		2.4
Financial Strength	FRISK score	5.52					10	7.5	5	2.5	0	8	20.0	5	50.0	2.5	75.0
													1.1		2.8		4.1
Currency Volatility	5-year stdev	4.61					0.1	1	10	100	>100	4	33.3	25	54.2	100	75.0
													1.5		2.5		3.5
FDI Investment	FDI scale	1.64					T1	T2	T3	T4	OTHER	T2	25.0	T4	75.0	T2	25.0
													0.4		1.2		0.4
International Trade Compliance	Survey	7.84					0	25	50	75	100	10	10.0	30	30.0	50	50.0
													0.8		2.4		3.9
GLOBAL RISK SCORE		30.00											6.9		12.4		14.4

Engineering Risk:

Global Risk	TLC																
Perf Risk	Analyze																
			Scoring Scale									1		2		3	
Engineering Risk Worksheet	Units	Weight	100	75	50	25	0	25	50	75	100	XXX	Score	YYY	Score	ZZZ	Score
Supplier Technical Capability	Survey	2.09					5	4	3	2	1	3	50.0	5	0.0	2	75.0
													1.0		0.0		1.6
Average YoY Growth (5 year)	%	0.46					10	5	3	1	0	7.7	11.5	12	0.0	3	50.0
													0.1		0.0		0.2
Years in Business	# years	0.46					10	7.5	5	2.5	1	9	10.0	4	60.0	4	60.0
													0.0		0.3		0.3
Years of Experience with Material Class	# years	0.46					10	7.5	5	2.5	1	4	60.0	2	83.3	1	100.0
													0.3		0.4		0.5
Fortune 500 Customers	# customers	0.46					>=1				0	1	0.0	2	0.0	0	100.0
													0.0		0.0		0.5
Supplier Organizational Competency:	Survey	1.81											18.8		0.0		37.5
a) Assigned First-Tier Rep?							Y				N	Y		Y		Y	
b) Global Contacts?							Y			N		Y		Y		N	
c) Regional Contacts?							Y		N			Y		Y		Y	
d) Designated Service Org?							Y			N		N		Y		N	
													0.3		0.0		0.7
Supplier Sub-Tier SCM:	Survey	1.48											18.8		37.5		43.8
a) Defined Purchasing Function?							Y				N	Y		Y		N	
b) Defined Quality Engineering Team?							Y			N		Y		N		N	
c) Supplier Metrics in Place?							Y		N			Y		Y		Y	

													0.3		0.6		0.6
Supplier Progressiveness:	Survey	1.17											50.0		0.0		100.0
a) 6-Sigma							Y				N	N		Y		N	
b) Lean Manufacturing							Y				N	Y		Y		N	
c) Safety							Y				N	Y		Y		N	
d) 5S							Y				N	N		Y		N	
													0.6		0.0		1.2
Research & Development:		1.63											28.3		33.3		46.7
a) Historical Customization Projects	# Projects						10	7.5	5	2.5	0	4	60.0	5	50.0	3	70.0
b) Dedicated R&D Resources?							Y				N	Y	0.0	Y	0.0	Y	0.0
c) NPI Capability	Survey						0	25	50	75	100	25	25.0	50	50.0	70	70.0
													0.5		0.5		0.8
ENGINEERING RISK SCORE		**10.00**											**3.1**		**1.8**		**6.2**

Performance Risk:

aVoila — Global Risk | ENG Risk | TLC | Analyze

Performance Risk Worksheet	Units	Weight	Scoring Scale 100	75	50	25	0	25	50	75	100	1 XXX	Score	2 YYY	Score	3 ZZZ	Score
Capacity Utilization	%	7.26	15	30	45	60	75	80	85	90	100	65	16.7	45	50.0	30	75.0
													1.2		3.6		5.4
Inventory Management	Survey	7.25					0	25	50	75	100	50	50.0	30	30.0	90	90.0
													3.6		2.2		6.5
Process Quality	Survey	3.97					0	25	50	75	100	25	25.0	60	60.0	25	25.0
													1.0		2.4		1.0
Preferred Carrier?		14.02					Y				N	Y	0.0	N	100.0	Y	0.0
													0.0		14.0		0.0
Product Quality	Survey	7.51					0	25	50	75	100	25	25.0	75	75.0	40	40.0
													1.9		5.6		3.0
GLOBAL RISK SCORE		**40.00**											**7.7**		**27.8**		**16.0**

Total Landed Cost:

aVoila — Global Risk | ENG Risk | Perf Risk | Optimize

Total Landed Cost Worksheet	1 XXX	2 YYY	3 ZZZ			
Annual Demand (units):	**444**	**444**	**444**			
Order Frequency (weeks):	**5**	**5**	**5**			
Unit Price (€)	**55.00 €**	**70.00 €**	**44.00 €**			
Unit Weight (kg)	**5**	**5**	**5**			
Location						
Country/Region of Origin (FG):	**Afrique du Sud**	**Israel**	**Etats-Unis**			
Ship To Location:	**SNZ**	**SNZ**	**SNZ**			
Transportation						
Shipping Method:	**Air**	**Air**	**Ocean**			
Average Lead Time (weeks):	**2**	**3**	**4**			
MAX Lead Time (weeks):	**4**	**4.5**	**5.5**			
Units/Carton:	**5**	**5**	**5**			
Packaging Cost/Carton (€):	**150.00 €**	**150.00 €**	**150.00 €**			
Carton Height (cm):	**60**	**60**	**60**			
Carton Length (cm):	**80**	**80**	**80**			
Carton Width (cm):	**60**	**60**	**60**			

Expedite Multiplier	2.5	4	3			
Expedite %	3	3	3			
Freight Paid by Supplier (Y/N)	N	N	N			
Duty Paid by Supplier (Y/N)	N	Y	Y			
Duty (per shipment)	200.00 €	200.00 €	200.00 €			
Customs Clearence Fee (per shipment)	50.00 €	50.00 €	50.00 €			
Fuel Surcharge (per shipment)	500.00 €	500.00 €	500.00 €			
Hazmat (per shipment)	0.00 €	0.00 €	0.00 €			
Harbor Maintenance Fee (per shipment)	50.00 €	50.00 €	50.00 €			
Other Assessment Charges (per shipment)	0.00 €	0.00 €	0.00 €			
Financial:						
Payment Terms:	Net 30	Net 60	Net 45			
Discount (%):	1	2	1			
Days for Discount:	5	10	7			
Inventory Management (Deterministic):						
First-Tier supplier owns inventory (Y/N)	Y	Y	Y			
First-Tier supplier pays on shipment/receipt?	shipment	receipt	shipment			
Lower Bound Yield (%):	50	60	70			

Average Yield (%):	80	75	85			
Order Point:	44.40	44.19	54.01			
Safety Stock:	27.32	18.57	19.85			
Process Stock:	17.08	0.00	34.15			
Investment:						
Assistance Fees (over time horizon):	0.00 €	50,000.00 €	0.00 €			
Tooling Contribution (+Depreciation, time horizon):	100,000.00 €	0.00 €	0.00 €			
One Time Charges:	50,000.00 €	20,000.00 €	40,000.00 €			
Engineering Qualification Needed (Y/N):						
# of Personnel:	3	5	2			
# of RequiredVisits:	5	5	5			
Length of Visit (Days):	5	5	5			
Estimated Cost/Person/Day (€)	500.00 €	700.00 €	1,000.00 €			

Appendix II: aViolà Supplier Survey

Supplier Evaluation Survey

	Global Risk	Description	Response
1	Geopolitical	Please provide the AON risk level for the supplier's region	
2	Supplier Revenue	Percentage of Second-Tier supplier's revenue that First-Tier supplier will represent	
3	Financial Strength	Supplier's FRISK score, a measure of bankruptcy risk	
4	Currency Volatility	Calculate 5-year standard deviation of supplier's primary currency (against USD)	
5	FDI Investment	Measure of Foreign Direct Investment in country (from ATKearney)	
6	International Trade Compliance	Please indicate if supplier has import and export experience with the subjects listed on the left (Y/N)	
6A	Valuation of shipments		
6B	Use of commodity codes		
6C	Invoicing for international shipments		
6D	Marking of goods based on customer specification		
	Engineering Risk	**Description**	**Response**
1	Supplier Technical Capability	Please indicate supplier's experience with or implementation of each of the items to the left (Y/N)	
1A	E-mail		
1B	Fax		
1C	MRP		
1D	CAD		
1E	Electronic Receipt Submission		
1F	Order Management System		
1G	Enterprise Resource Planning System		
1H	Data Backup		
1I	Barcode Tracking (P/N compliance)		
2	Average YoY Growth	Average % Growth Experienced over the last 5 years	
3	Years in Business		
4	Years of Experience with Material Class		
5	# of Fortune 500 Customers		
6	Supplier Organizational Competency	Y/N	
6A	Assigned Rep to First-Tier supplier?		
6B	Global Contacts?		
6C	Regional Contacts?		
6D	Designated Service Org?		
7	Supplier Sub-Tier SCM:	Y/N	
7A	Defined Purchasing Function?		
7B	Defined Quality Engineering Team?		
7C	Supplier Metrics in Place?		
7D	Robust Disruption Recovery Plan?		
8	Supplier Progressiveness:	Which of the following programs have been implented in the supplier's organization?	
8A	a) 6-Sigma		
8B	b) Lean Manufacturing		
8C	c) Safety		
8D	d) 5S		
9	Research & Development:	Please indicate if the supplier's organization demonstrates the capability to develop and test new engineer designs	
9A	a) Historical Customization Projects		
9B	b) Dedicated R&D Resources?		
9C	c) NPI Capability		
	Performance Risk	**Description**	**Response**
1	Capacity Utilization	Current capacity utilization, without the new business being quoted, for the facility where supplier will manufacture	

2C	Warranty Terms?	When does the warranty period begin? At manufacture date, install to the aircraft, or sale to customer?	
2D	Packaging?	Shipping individual parts or an assembly?	
3	Process Quality	Please indicate which of the capabilities listed on the left are utilized by the supplier to ensure process quality?	
3A	ISO Certified		
3B	ISO Compliant		
3C	Specification Documents		
3D	Corrective Action Plans		
3E	Formalized Document Control Processes		
3F	Inventory Segmentation for defects		
4	Preferred Carrier utilized?	Are First-Tier supplier's preferred carriers available at the shipping location?	
5	Product Quality	Please indicate which of the capabilities listed on the left are made available by the supplier?	
5A	DPPM or rejection rate tracking		
5B	Yield anlalysis		
5C	Delivery Performance Tracking		
5D	Part Failure Rates		

	Total Landed Cost	Description	Response
1	Order Frequency (weeks):	How often will an order be placed (may follow EOQ or JIT dependant on item)?	
2	Unit Price (€)	Cost per unit	
3	Unit Weight (kg)	Weight per unit	
	Location		
4	Country/Region of Origin (FG):	Supplier shipping location	

5	Ship To Location:	Site that will receive goods	
	Transportation		
6	Shipping Method:	Air/Ocean/Ground	
7	Average Lead Time (weeks):	Average time from shipment to receipt	
8	MAX Lead Time (weeks):	Maximum expected time from shipment to receipt	
9	Units/Carton:	Number of units that will fit in a carton	
10	Packaging Cost/Carton (€):		
11	Carton Height (cm):		
12	Carton Length (cm):		
13	Carton Width (cm):		
14	Expedite Multiplier	Estimated multiple of standard transport cost First-Tier would pay for an expedite	
15	Expedite %	Estimated percentage or shipments that would need to be expedited	
16	Freight Paid by Supplier (Y/N)	Does First-Tier pay Freight cost, contractually? (Y/N)	
17	Duty Paid by Supplier (Y/N)	Does First-Tier pay the duty, contractually? (Y/N)	
18	Duty (per shipment)		
19	Customs Clearence Fee (per shipment)		
20	Fuel Surcharge (per shipment)		
21	Hazmat (per shipment)		
22	Harbor Maintenance Fee (per shipment)		
23	Other Assessment Charges (per shipment)	Any unaccounted transportation costs	
	Financial:		
24	Payment Terms:	Accounts Receivable payment terms: Net 30, Net 45, or Net 60	
25	Discount (%):	Discount provided for early payment	

26	Days for Discount:	Days allowed until payment in order to receive discount	
	Inventory Management (Deterministic):		
27	First-Tier supplier owns inventory (Y/N)	Does First-Tier supplier own all inventory? (Y/N)	
28	First-Tier supplier pays on shipment/receipt?	Does First-Tier supplier pay for goods on shipment or receipt?	
29	Lower Bound Yield (%):	What is estimated lower bound on yield for the material being sourced?	
30	Average Yield (%):	What is estimated average yield for the material being sourced?	
	Investment:		
31	Assistance Fees (over time horizon):	Any foreign engineering provided free or at reduced cost by First-Tier supplier, and used in the Second-Tier supplier's production.	
32	Tooling Contribution (+Depreciation, time horizon):	Any tooling contribution First-Tier supplier makes to enable Second-Tier supplier.	
33	One Time Charges:	Fixed costs at startup that do not otherwise fall in any category.	
	Engineering Qualification Needed (Y/N):		
34	# of Personnel:		
35	# of RequiredVisits:		
36	Length of Visit (Days):		
37	Estimated Cost/Person/Day (€)		

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