Risk Management Framework for Evaluating Suppliers

by

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B.C.E., Computer Engineering, University of Delaware, 2001

Submitted to the MIT Sloan School of Management and the
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and
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Abstract

Sikorsky Aircraft Co. currently finds itself in a critical growth period, in terms of both sales contracts and supplier agreements. Popular supply chain strategies preach reduction and simplification of the supply base, but Sikorsky encounters "must-grow" situations with their supply base, due to factors like international offset provisions and capacity needs. Growth in the number of supplier relationships each year strains the supply management department and makes it difficult to complete full analyses of new suppliers. The goal of this research is to provide tools that combine the knowledge of experienced supply chain employees with statistical analysis in a package that will allow any member of the supply chain group to complete a thorough supplier risk analysis in the minimum amount of time.

To address Sikorsky's supply chain risk, a concrete framework is desired that will ask the right questions about a supplier and produce an indicator of the level of risk involved in a supplier agreement. This project sets out to identify the connections between the sources of risk (risk drivers) and affected performance metrics (effects). These connections can be presented in an easy-to-use tool that enables quick yet thorough analyses. The framework links supplier analyses with the resulting performance, and uses the results to make data driven inferences about future supplier relationships. This allows quick and informed assessments by anyone in the supply chain group, regardless of their level of experience.

The result of this project is a software-based risk assessment framework with scoring based on historical Sikorsky supplier performance. The data have revealed through statistical regression analysis strong correlations between a number of risk drivers and resulting supplier performance. These correlations can be used to score suppliers with similar attributes through the model. In addition, the model can be used as a knowledge retention mechanism of supplier performance data to facilitate future refinements of both the model and risk driver/effect correlations.

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Chapter 1: Project Overview

The words "outsourcing" and "globalization" are as popular in business circles as they've ever been, and companies like Sikorsky are starting to feel the effect of getting farther and farther from their sources of supply. As economies grow and emerging markets enter the global marketplace, Sikorsky is finding larger and larger audiences to sell goods and services beyond their native region, country, and even continent. Sikorsky must now decide how much of this new business they want to pursue and consequently how many suppliers should be added to enable sales to these new markets. When new markets are pursued, should they try to keep their list of suppliers short, or expand the supply base into developing countries where costs may be lower, but risks may also be higher? Despite observed industry trends of supply base reduction (Goffin, Szwejczewski and New, 1997), arguments can also be made for supply chain redundancy to mitigate the effects of supply disruptions, for instance (Sheffi, 2001). Generally, "it can be seen that, whilst there is general agreement on the reduction of multi-sourcing networks, there is a range of views on the relative merits of single and multi-sourcing." (Harland, 1996) The advantages of each view have been summarized in Table 1. Sikorsky, however, must partially ignore many of these arguments as they are now faced with situations where their business specifically requires growth in the supply chain. One example of this forced growth is with international offset arrangements, where "Countries are requiring more technology transfer, higher offset percentages, and higher local content requirements to offset their foreign military purchases (U.S. General Accounting Office, 1996)." The "local content requirements" cited above are the source of this supplier growth. This demands a larger focus on the issue of risk in the supply chain and selecting the "right" suppliers.

Advantages of Broad Networks	Advantages of Narrow Networks
Adaptable to Change	Collaborative Innovation
More switching opportunities	Rigid and Strong
Wider access to knowledge	Dense flows of information
Hedge against uncertainty	Higher confidentiality
Cost competitive	Shared Destiny

Table 1 - Relative merits of broad versus narrow supplier networks (Harland, 1996)

Like forecasting, risk assessments are never an exact science and can never predict the future. However, they can be used as learning tools. If created correctly, they can help see past biases and broken mental models to reveal risks that have been right under the noses of everyone involved. Such tools aim to work by stimulating thought and research, not by predicting what will happen. It is in these respects that this research attempts to ask objective questions and provide objective answers to help start the process of managing the risk in a supply chain.

This chapter has been decomposed into several sections providing an overview of the research process. It starts with a brief problem statement to set the tone of the following work and provide further context into the motivation behind the work. Background information about Sikorsky and Sikorsky's parent company, United Technologies Corporation follows the problem statement. The discussion then moves on to a description of the group, supply management, where the research project work was conducted and a description of the problem to be addressed. The overview wraps up with a discussion of the project deliverables and methods used to create the deliverables. In-depth analyses of the methods used are provided in subsequent chapters.

Problem Statement

There are inherent risks in evaluating a contract with an international supplier/partner. These risks can be broken into the categories of scheduling, technology, and cost uncertainty (Sinha, Whitman, and Malzahn, 2004):

- Schedule risk is the probability that the supplier will not deliver on time
- Technology risk is the probability that the supplied goods or services do not meet the performance and quality standards as specified
- Cost risk is the probability that the goods or services will not be delivered at the price that was agreed upon when the order was placed

As a company's supply base grows to support new sales contracts, the management and assessment of those risks becomes increasingly complicated. A concrete framework is desired for quantifying and speeding up the assessment of the risks associated with such an endeavor. This project sets out to identify and quantify the risks involved to hopefully distill out a numerical score and a course of action that can be used to evaluate a supplier. "The purpose of risk analysis is to develop a structured way of defining, identifying, assessing, and mitigating the risks." (Sinha et al, 2004). In this research, the focus will be on identifying and assessing risk.

As discussed above, Sikorsky Aircraft finds itself in a time of significant growth in the supply chain. In many cases, proliferation of the number of suppliers in a company's supply base is something that would be controlled and limited. However, in this situation, Sikorsky is required to add suppliers to fulfill offset, small disadvantaged business, and other related mandates that have been put in place. Therefore, they require a tool that will consolidate all of the risk management resources at their disposal and provide easy methods for monitoring and assessing the risk in the escalating number of supplier contracts.

At Sikorsky there are numerous methodologies that have been developed in house or acquired externally to monitor different aspects of a supplier relationship. In the case of Sikorsky, specifically, there is a separate tool for the quality group to record the quality record of a supplier, a separate tool for the supply chain group to monitor the delivery performance of a supplier, a separate third-party software program for supply chain employees to monitor other aspects of a supplier relationship, etc. These tools all contain data that is useful in monitoring the performance of a supplier, but they are all used individually by their own groups. It would be useful for the supply chain group to look at every source of data together when evaluating a supplier. In addition, very few of these methods are useful when used by themselves to evaluate a new supplier. It is only through the integration of these tools that a true evaluation can be conducted. It is apparent that if there was one place where all of this data was gathered for evaluating a supplier it would speed the process and help to avoid the "silo"-ing affect that occurs (where all data is kept in its own silo). Supplier decisions could be made based not just on the data that matters to purchasing (on time delivery), but also by integrating metrics that serve other parts of the organization (quality, customer service).

Corporation Background

To provide context for the issues and challenges inherent in this project, a brief overview of Sikorsky aircraft's and United Technologies Corporations' history and corporate culture are appropriate. These reviews will cover the past and present states of these business entities and hopefully paint a more complete picture of the competitive landscape that Sikorsky is participating in.

United Technologies Corporation

In its current state, United Technologies Corporation is a major multinational corporation with business units in the aerospace, heating ventilation and air conditioning (HVAC), Fuel Cells, Fire Suppression, Security, elevators, escalators and other related technologies that earned $47.8 billion in 2006 revenues with rankings that include the 20th largest U.S. manufacturer (2006 list, *Industry Week*), 43rd largest U.S. corporation (2006 list, *Fortune*), and 126th largest corporation in the world (2006 Global 500 List, *Fortune*)[1]. The beginnings of United Technologies are complicated, but the first of the current United Technologies business units to be created was the Otis Corporation under Elisha Graves Otis, who demonstrated his invention of an elevator with a safety mechanism to prevent falling at the New York World's fair in 1853. However, Otis was not acquired by United Technologies until 1976. The United Technologies Corporation actually evolved from United Aircraft, which was created in 1934 when United Aircraft and Transport was dissolved. United Aircraft and Transport Corporation was considered anti-competitive by the U.S. government, due to newly passed antitrust laws that forbade airframe or engine manufacturers from having interests in airlines. At this time United Aircraft and Transport Corporation included Boeing Airplane Company, Hamilton Aero Manufacturing, Pratt & Whitney Aircraft Company, Sikorsky Aviation Corporation (now Sikorsky Aircraft) as well as United Airlines[2]. After the dissolution, United Aircraft Corporation was established consisting of Pratt & Whitney, Sikorsky, Hamilton Standard (now part of Hamilton Sundstrand), which are all current business units of United Technologies Corporation. Since that time, United Technologies has grown considerably and acquired multiple companies. United Technologies Corporation now boasts over 215,000 employees in over 4,000 locations, in approximately 62 countries. The full list of current business units is:[3]

Carrier heating and air conditioning systems

Hamilton Sundstrand aerospace and industrial systems

Otis elevators and escalators

Pratt & Whitney aircraft engines

Sikorsky helicopters

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[1] http://www.utc.com/profile/facts/index.htm (March 30, 2007)
[2] http://www.utc.com/profile/facts/history.htm (September 11, 2006)
[3] http://www.utc.com/profile/facts/index.htm (March 30, 2007)

UTC Fire & Security protection services

UTC Power

United Technologies Research Center

Sikorsky Aircraft Corporation

Started in 1923, the Sikorsky Aero Engineering Corporation (changing its name a number of times until settling on The Sikorsky Aircraft Corporation) is the result of nearly a lifetime of aerospace research and development by Igor Sikorsky. Born in Kiev on May 25, 1889, Sikorsky's early captivation with the works of Leonardo DaVinci and stories of Jules Verne led him to build a rubber band powered model helicopter at the age of 12. After engineering study and experiments in a German hotel room on a 4 foot diameter helicopter rotor, Igor Sikorsky built a coaxial twin-bladed rotor helicopter in 1909. This helicopter never actually flew, as engineering calculations revealed that the aircraft only produced 357 pounds of lift, 100 pounds less than the weight of the aircraft.

At this point Sikorsky turned his attention to fixed wing aircraft and after brief stints as an aircraft engineer in Russia and France, he arrived in New York on March 30th, 1919. It wasn't until 1923 that Sikorsky was able to begin working on aircraft again, when he raised funds for an all-metal, twin-engine passenger plane. The Sikorsky Aero Engineering Corporation was formed on a farm in Long Island. Igor Sikorsky went on to create several notable aircraft, including the eight-seat S-36 which entered service with Pan-American Airways in 1928 and the nine-passenger S-38 which drew orders from 10 airlines. The continued success with passenger aircraft led to the acquisition of Sikorsky Aviation Corporation as a subsidiary of the United Aircraft Corporation in 1929.

Igor Sikorsky finally had sufficient support to resume work on helicopters and did so in 1931 when he patented the current most common configuration: 1 main rotor and 1 tail rotor to offset the torque caused by the main rotor. The open cockpit VS-300 helicopter flew for the first time in 1939. The progress from there was rapid and in WWII, cloth covered Sikorsky helicopters were flying combat rescue and Medevac missions[4].

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[4] http://www.sikorsky.com/details/0,9602,CLI1_DIV69_ETI683,00.html (September 11, 2006)

Now, Sikorsky helicopters are operated by all five branches of the United States Armed forces as well as operators in 40 countries around the world. Boasting revenues of $2.8 Billion in 2005[5], Sikorsky is the company behind the workhorse UH-60 Blackhawk line of helicopters and the successful S-92 commercial helicopter. By the end of 2006, Sikorsky helicopter hoped to fly a demonstration of their revolutionary X-2 helicopter technology, which will utilize two counter-rotating rotors on the same axis and auxiliary propulsion to cruise at 250 knots.

International Supply Management

Background

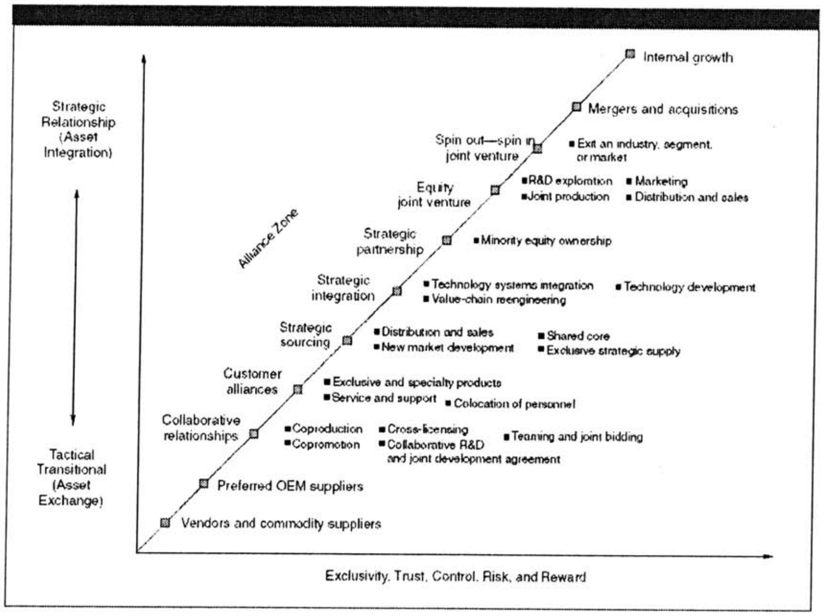

Figure 1 - Strategic outsourcing relationship continuum (Blumberg & Miller, 2002)

The international supply management group in Sikorsky Aircraft is responsible for initiating and managing outsourcing agreements ranging from simple vendor relationships to strategic integration. These arrangements can be displayed along an outsourcing relationship continuum as displayed in Figure 1 (Blumberg & Miller, 2002). Though each of these agreements requires a different level of cooperation by each party, all are handled within the same group within Sikorsky. The group is managed by three individuals and supported by buyers, who handle both international and domestic contracts. The buyers generally do not get involved until a supplier has signed on to supply parts and/or services, so it is essentially the job

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[5] UTC 2005 Annual Report

of three people to initiate contact and manage the contracting process for every international supplier. Only after a company goes through the process of being evaluated and eventually becoming a supplier, they are eventually assigned to a buyer for general contact.

Issues and Concerns

As mentioned, the number of suppliers is growing rapidly each year, where a large portion (greater than one third) is international suppliers. This growth puts an enormous strain on the international supply management group, and hinders their ability to spend sufficient time evaluating each new supplier. There are two key drivers behind this massive growth in recent years: *growth in number of projects and international offset provisions.*

Though Sikorsky has not seen a large proliferation in the number of helicopter models they manufacture, the number of configurations that are provided to various countries has grown considerably. This pushes the capacity of Sikorsky's manufacturing operations to the limit and has increased the percentage of the aircraft considered for outsourcing. As mentioned earlier, higher levels of cooperation are used in recent co-production agreements as well. Outsourcing and co-production of aircraft parts will sometimes go to a current supplier, but in most cases a new supplier must be signed. As the United States is considered a high-cost nation in terms of fabrication and assembly, Sikorsky has sought out increasing numbers of international suppliers to control costs as much as possible. A table of manufacturing labor wages is provided as Table 2[6].

Country	Labor Cost ($/hour)
Germany	$21.68
Spain	$16.73
United States	$15.31
Israel	$12.99
Japan	$10.36
Singapore	$9.20
Taiwan	$5.11
Hungary	$3.82
Poland	$3.56
Czech Republic	$2.95
Romania	$1.74

Table 2- International Manufacturing Wages[6]

[6] International Labour Organization Data (http://laborsta.ilo.org/) Table 5B, Economic Activity 35, year 2004

Besides seeking cheaper labor and added capacity, the growth of global sales has also created a push for more international suppliers, due to international offset provisions. These offset provisions are often required by foreign governments and stipulate that if Sikorsky wishes to sell aircraft to a foreign nation, a portion of the aircraft must be manufactured in that nation, purchased in that nation, or some amount of work provided in that nation. This complicates the sales effort within Sikorsky as sales to a new nation may create the need in supply management to bring in new supply agreements. Thus the recent growth within Sikorsky of foreign sales contracts has created a wave of suppliers that must be in specific foreign nations.

Handling this growth has created a strain in the international supply chain department. Therefore, the department has the need for a tool or methodology that can quickly and efficiently do a baseline analysis of potential risks in a supplier relationship without taking up too much of the time of the management and buyers of the group. Though this research was conducted based on the challenges of the international procurement group, the results will be applicable to the supply chain group as a whole.

Deliverables

There are three major deliverables for this research project: an initial framework for supplier risk assessment, a framework improvement method, and a rollout plan. All of these deliverables are focused on the framework itself, but they bear individual mention due to the fact that the framework itself will only provide assessment for a short period of time. It is the standardization of the assessment as well as the ability to augment the framework over time that will allow the supplier evaluation framework to become and remain a viable tool.

Risk Assessment Framework

The framework has been constructed such that a number of questions about the supplier, the contract, and global metrics (i.e. labor rates, exchange rates) will reveal areas of risk regarding a supplier relationship. These questions have been finely tuned to be both easy to answer at the time of supplier assessment, yet provide insight into features of a company that have proven risky. The overall goal within the framework was to provide a platform that would be familiar to all users, yet contain the logic necessary to infer the effects of the characteristics in a supplier agreement.

Microsoft Excel was chosen as the environment the tool would reside in for a number of reasons. The first of these is that it is a known platform that everyone in the Supply Management department of Sikorsky already knows how to use and does use on a daily basis. This will make it possible for use and modification to be accomplished by anyone in the group, not just a select few. Beyond the fact that everyone in the group has a high level of competence with the tool is the simple fact that everyone already has the software installed on their desktop PC. This avoids a number of support issues as well as IT issues with gaining permission to install new software.

Framework Improvement Methods

The framework provides a starting point, but will not provide accurate assessment forever. To ensure that the risk scores computed by the framework are accurate over time, it must be updated regularly to take into account new trends and experiences with Sikorsky suppliers. To accomplish this, instructions have been provided to allow Sikorsky to make these updates as effortlessly as possible. These instructions include technical guidance on how to physically update the spreadsheet and roll out the changes as well as practices for use in the company to both improve the effectiveness of the model as well as facilitate easy updates in the future.

The technical instructions mentioned focus mainly on types of locations on servers where the framework should reside, the commands to use to update the format of the framework, the tools to use to update the scoring of the framework, and others. Though the environment is familiar to everyone using the tools, the concepts and structures used in the framework may not be. Therefore, the technical instructions are clear and concise to enable regular updating of the model.

Beyond the technical instructions, recommended practices are provided to improve the effectiveness of the model. In many cases these practices focus on increasing the volume of data passing through the model. This includes gaining wider use, saving data for a longer time horizon, and practices for adding questions over time as new trends arise.

Rollout Plan

As with most standard practices, a well designed rollout plan is necessary to ensure that the framework gets the correct audience and is correctly used. Far too many implementations of tools fall by the wayside because they do not clearly present a case for addressing the issues facing the users or they are not properly supported. The rollout plan created for this project focuses on empowering the main users of the tool and streamlining their supplier analysis. In addition the rollout plan will mandate support mechanisms to ensure those with problems don't have to wait long for help; the longer a user has to wait for help, the more likely they are to lose faith in the tool and drop it.

Methodology

The methodology followed here involved four major steps: developing a risk list, creating a framework, scoring the framework, generating standard work and procedures.

Risk List

Before any framework could be created, an in-depth analysis of the risks facing the supply management group at Sikorsky was necessary. For the purposes of this exercise, a risk was defined as the risk of poor performance from a supplier. First, interviews with members of the supply management group were conducted to assess which risks were apparent to members of the groups. In addition to a discussion of the effects of risk in a supplier relationship, factors that may contribute to a performance risk (risk drivers) were listed as well. Once this first-pass list was created, it was reviewed and appended with factors from case studies of real Sikorsky experiences as well as research in scholarly journals. The processes followed, as well as the risk effects to focus on are based on work by Sinha et al. (2004). The risk effects are based on those presented as "scheduling, technological, and cost uncertainty" in their work, but will be called more specifically in this research delivery, quality, and cost, respectively. In addition, the risk list generation follows the Sinha et al. (2004) Activities 1-3 of Brainstorming, Identifying Risks, and Classify Risks. These activities were repeated in an iterative fashion until further iterations yielded no additions, at which point a final listing of risk drivers was created. The resulting drivers were divided into four major categories: Financial Factors, Design Factors, Operations Factors, and Business Factors.

Framework Creation

After the final list of risks was created, the focus turned to developing a framework that provided a path for identifying and assessing these risks effects and drivers for a specific supplier and contract. The requirements were that the framework be quick, concise, easy to use, and able to provide clear results. Based on these requirements, a platform would first need to be selected, then the format of the framework, and finally the way in which results would be conveyed.

In selecting the platform, a computer based approach was selected immediately for numerous reasons, not the least of which being the easier retention and modification of electronic data. Immediately the platform options were limited by common IT practices as well as employee daily usage. Many IT managers keep tight control over which software can and can not be installed on user computers. Therefore, software that users already had on their PCs would be highly advantageous. In addition, the users in the group used very few computer tools on a day-to-day basis. These included SAP ERP software, Microsoft Office products, and web based tools. Therefore, the decision was made to focus the platform on one of these three tools. Of these three tools, Microsoft Office Excel was selected as the platform, due to the ease of use, familiarity of the employees, easy modification, and low effort required in programming interfaces. The closed nature of the SAP and web based approaches, would be more mistake proof and avoid modification errors, but both approaches stifle the ability to change framework structure quickly and easily by anyone in the group and would have required more programming effort. The Microsoft Excel approach provides quick turnaround for changes, ease of use between users, and an easily expandable system with little IT effort.

With a platform selected, the next area of focus rested on the format. Once again, the format needed to be easy-to-use, quick, concise and able to provide clear results. The very common questionnaire format can accommodate all of these features and also provides a format that most users are familiar and comfortable with. A simple data entry screen may have been sufficient, but some of the metrics used in the analysis may be interpreted differently for different suppliers and contracts. Therefore, a questionnaire gives the author more freedom to define the questions and expected responses.

The process for the next step of formulating the questions for the questionnaire was very similar to the way in which the risk list was created. First, in a brainstorming session, one or more questions were created for each risk driver. Each question was selected such that it would provide as accurate a measure of how each risk driver applies to the supplier contract as possible. After this initial list, an iterative process that included interviews, pilot studies and more brainstorming was used to refine the questions. The goals of the refinements were that the number of questions was minimal, the data needed for the question is readily available to the user, and the result directly applies to a risk driver.

Once the question list was created, a link between the questions and expected performance was necessary. A statistical regression model was identified as a suitable method for identifying these links. Statistical regression models are a widely used and studied approach and thus serve as a standard for analyzing the effects of the process to some stimulus. A similar approach was used by Tan, Kannan, Handfield, and Ghosh (1999), where a regression model was used to determine the effect of supply chain management techniques on overall company performance. In our system, however, the effect is poor supplier performance in the areas of cost, quality and delivery, while the stimuli are characteristics of the supplier, contract, and global economy. To use a regression, a large amount of representative data was needed. Once this data was obtained statistical modeling tools could be used to analyze the links between the effects to the stimuli. In the case of this project, a sampling of current and past Sikorsky suppliers was collected. The questionnaire was then filled out for each of these suppliers as if they were being assessed at the beginning of their contract. Then, the resulting performance metrics of that supplier were gathered for the length of the contract. This data coupled with the statistical modeling tools provided weighting for the questions that revealed a correlation. These weights were then used in the framework to provide a scoring based on the answers to the questions.

Once the correlations were identified and the framework was able to score the factors that posed the greatest risk, these risk scores needed to be displayed in the most usable way possible. The decision was made to present the score using a single value between 1 and 10 for each major risk driver category described above, and one overall value between 1 and 10. Narrowing the risk "score" down to single value removes a fair amount of resolution from the result, but that is by design. Overall, this approach is not meant to predict the future of a supplier relationship; it is only meant to provide a "red flag" of whether there are areas of concern. That is the intent of this single value.

Chapter 2: Risk Evaluation Framework Details

The risk evaluation framework is meant to address the supplier evaluation needs of the international supply management department and beyond. While remaining within the parameters of being concise, quick, easy and accurate for supplier evaluation, the goals of the framework include having an impact beyond the supply management department. An overview of the framework was provided in previous sections. This section focuses on the detailed work performed and the results obtained. The discussion begins with a brief section to reemphasize the goals of the framework. The following sections provide a list and descriptions of the tools integrated into the analysis, details about the structure of the framework, in-depth analyses of the risk factors included. The section then closes with the development and results of the scoring mechanism.

Framework Goals

First and foremost, the framework addresses the needs of the international supply management group mentioned above. Constructed of a questionnaire of finely tuned questions, the framework attempts to cut through useless questions and focus on those that are both insightful into the expected performance of a supplier relationship and based on data that is easily available by buyers and managers within the supply management group at the time of supplier evaluation. In this way, the framework will act as a litmus test of a supplier where areas of concern will be quickly highlighted.

The goals beyond assessment lie in utilizing new data sources and providing a data retention tool for continued supplier analysis. The first of these secondary goals is a response to the fact that supply management uses only its own data sources, both electronic and non-electronic, when evaluating suppliers. Various other groups in Sikorsky have useful metrics and data that can be used to augment the analyses done within supply management. These sources, however, are not used regularly. In addition to other internal data sources, the framework reaches outside to a web based supply chain risk database. The supply management group does currently subscribe to this database, but actual use is rare. In this context, the goal is to apply other data sources to a supplier analysis and convert them into a number with a specific meaning to a supply management employee. A fitting example exists in the online supply chain database. It contains metrics for hundreds of thousands of companies with values that range from 1 (low risk) to 5 (high risk) for various aspects of performance. These numbers, however, have no specific meaning to someone in Sikorsky's supply management group (i.e. "What's the difference between a 2 and a 3 for on-time delivery?"). The framework will take these values and tie them to the performance of actual Sikorsky suppliers. Therefore, each value will be tied with a point of reference that is familiar in Sikorsky's context, like a previous supplier.

The next of these secondary goals is to have a platform for the retention of important supply chain data. This goal came to light as a result of the challenges encountered in data gathering for the initial framework scoring. When doing a retrospective analysis of a sampling of companies, much of the data that would easily be accessible at the time of analysis has been lost since that time. If this framework gains continued use and is stored, it can serve as the data source for future refinements of the model. It will also serve as a source of aggregated data. In looking at past analyses, a supply management employee will no longer have to gather data from separate resources. Rather, the data will be stored in one place, the framework.

Tools integrated into the analysis

As mentioned, a number of diverse data sources are included in the framework analysis. Below is a listing of these sources:

Online Database: An online supply chain risk database, whose real name has been concealed, supplies some of the answers to the questions in the framework. The reason this data source was included in the framework is explained briefly in the previous section; its values have little context for the average viewer, but the values are the result of real-world supplier performance. In the framework, the actual meaning on the performance values can be related to performance that has true meaning in Sikorsky's context. This database also has limited information about defect rates and delivery metrics for many of the suppliers. It also contains Lean Assessments that can be forwarded to suppliers and tracked on the site. The framework will use specific data from these sources when available.

Warning Signals: Warning signals is Sikorsky's internal supplier quality recording database. This data is gathered from Sikorsky assessments of delivered product from their suppliers. When reviewing a possible new contract for a past supplier of Sikorsky's, this data will prove useful in the analysis and offer data from the perspective of the quality group.

Supplier Delivery System: The supplier delivery system is yet another data source in Sikorsky that tracks and easily displays supplier delivery metrics. As with Warning Signals, this data source is useful in performing an analysis of current and past suppliers of Sikorsky.

Various Audits: Standard audits are performed by the supply management department for the government and other agencies. These audits cover topics such as capacity, cost, and licensing. Data from these audits also provide insights into the details of supplier contracts.

Free Online Resources: General trends and economic data easily obtainable on the web were included as well. Examples from this source are financial reports, exchange rates, and labor rates.

Framework

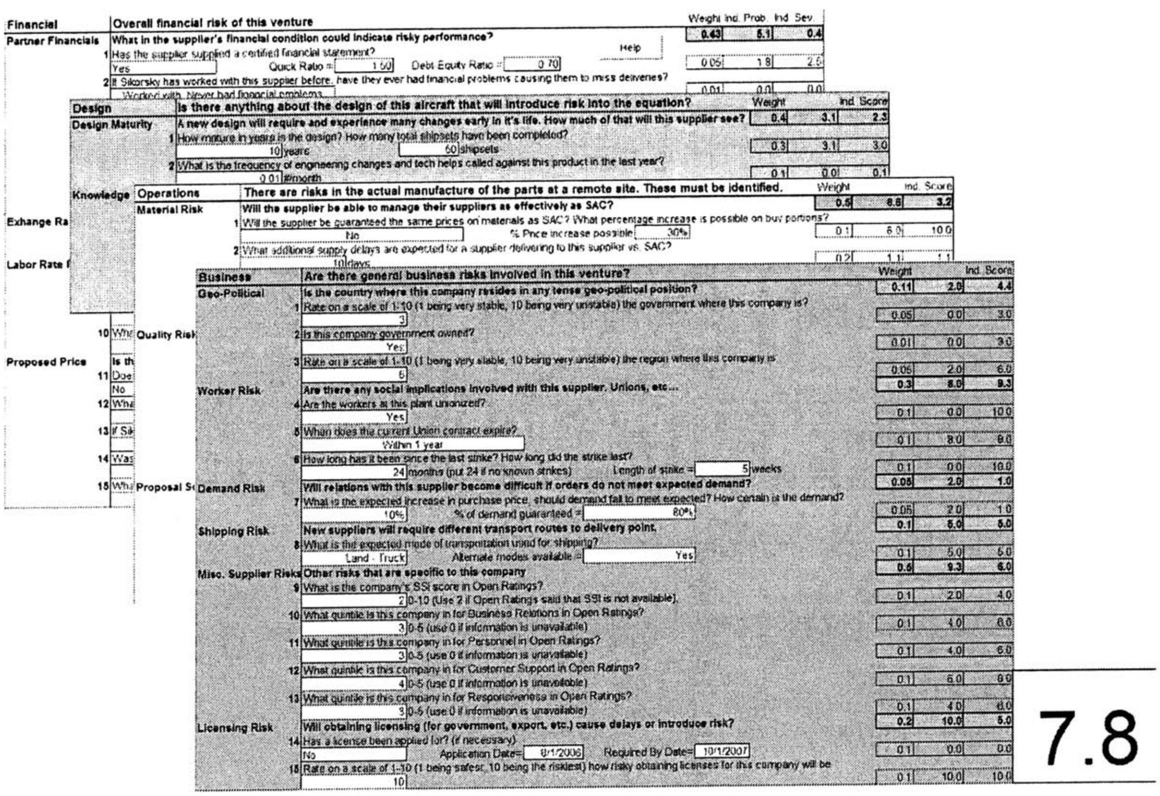

Figure 2 - Framework View

A compressed view of the risk framework is illustrated in Figure 2. In use, the four colored sections do not overlap, but rather lie one after another in the excel sheet. Each main risk group is highlighted with a different color; financial risks are green, design risks are blue, operations risks are yellow, and business risks are in red.

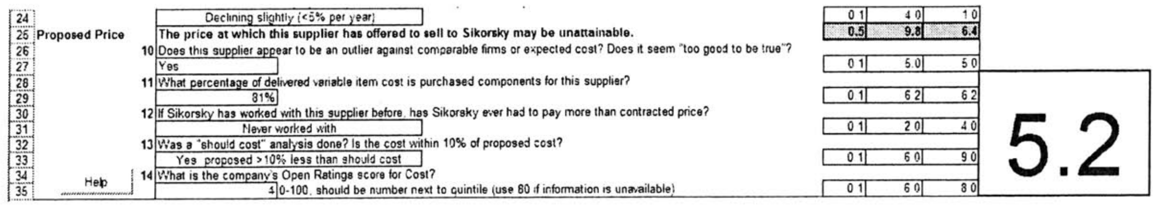

Figure 3 - Financial Group Closeup

Within each main risk group, the analysis is broken down further into key risk drivers within that category. These key risk drivers are indicated in bold text in the left pane of each risk group. An example can be seen in Figure 3, where "Proposed Price" is a key risk driver. Next to each key risk driver is a short description of what behaviors are covered by that risk. After the short description is a breakdown of the score for that key risk, in the form of three numbers highlighted in grey. The first number is the total weight associated with that key risk driver. The second and third numbers are the score for expected late delivery risk and expected quality defect risk, respectively. Listed below each bolded key risk driver are a number of questions that are used to generate the score. Each question is numbered and has a white area that serves as the response input. Responses take the form of drop-down selections and numerical inputs. Just like the key risk driver, each question has a score breakdown of weight and individual scores for late delivery risk and quality risk. The scores for each question are weighted and combined to form the associated key risk driver score. For example, in Figure 3 the scores for questions 10 through 14 fourteen are used to compute the score for "Proposed Price". Also, in the far left column are a number of "help" buttons. For a number of questions, help is provided by clicking the button next to the question. Help includes links to relevant data sources, equations, and instructions for formulating the answer to the question. Finally, at the bottom right of each main risk group is a single score for that group that is computed using the key risk drivers for that group. This score is color coded so that values below 5 are green (low risk), between 5 and 8 are yellow (medium risk), and above 8 are red (high risk).

Result **Time Weighted Result**

4.27 Update-> 4.54

History

Date	Time Weighted Score	Current Result	Financial	Design	Operations	Business	
9/26/2006	4.54	4.54	6.15	2.32	4.41	5.26	<-- After Last Update
6/26/2006	4.54	4.54	6.15	2.32	4.41	5.26	
9/26/2005	4.54	4.54	6.15	2.32	4.41	5.26	
9/26/2004	4.54	4.54	6.15	2.32	4.41	5.26	
9/26/2003	4.54	4.54	6.15	2.32	4.41	5.26	
9/26/2002	3.45	3.45	5.66	2.14	3.89	2.11	

Clear History

Figure 4 - Results Section

After the four main groups, there is a results section, as seen in Figure 4. This section facilitates continuous monitoring of a supplier. It includes the total result for the current responses, a time weighted result, and finally a history section of past scores. The time-weighted score is computed based on the current score, the previous time weighted score, and the amount of time since the last update. The effect is that short "spikes" in the results will be smoothed and longer trends can be watched. For instance, if the last time the score was updated was a year ago, the time weighted score will be almost identical to the current score (no smoothing will occur). However, if the model had been updated yesterday, the time weighted result will be more highly weighted to the previous time weighted score. Below these two scores, is a history of what the main group values were each time the time weighted score was updated.

Key Risk Areas

The lynchpin of creating an effective risk assessment is being able to generate a complete list of the possible risk areas. To facilitate this process, personal experience, past Sikorsky experience, and industry standard risk factors were gathered to construct as thorough a list as possible, without making the framework unwieldy. All risks were evaluated based on their effect on multiple supplier performance metrics.

The risks were divided into four main categories: Financial Risks, Design Risks, Operations Risks, and Business Risks. The Financial Risks all deal with the financial state and economic inputs of the supplier. These factors will mainly affect the price of the delivered product, but in some cases can actually cause a breach of contract (like the partner going out of business). Design Risks address the robustness of the design work completed at Sikorsky, if Sikorsky is the designer of the part. These factors address effect of design stability on final delivery as well as potential delays and cost overruns that may occur due to immature, inefficient, or incorrect designs. Operations Risks capture all of the risks inherent in the actual manufacturing work performed by the supplier for the agreement in question. It not only captures the partner's ability to deliver product on schedule, but also addresses whether the supplier has the capacity and ability to meet the demand of materials it has promised to manufacture itself. Finally, Business Risks address the general risks due in the business climate that could cause variability in the entire project. Covered in these risks are political, social, and licensing risks. These risks threaten to affect the supplier's entire business rather than this specific project. However, the effect on the business has the high likelihood of trickling down into the agreement Sikorsky has with the supplier.

Financial Risks

The goal for the financial risks is to capture not only the financial standing of the supplier but also the global conditions necessary to draw conclusions about their ability to deliver at the proposed price. Company financial reports as well as global factors like exchange rates will be considered to formulate a score for the financial viability of a contract in a specific supplier's hands. In addition, these partners may be very aggressive in their proposed costs. It will be necessary to analyze and compare these estimates to historical or competitive estimates to determine if they are realizable. Risk drivers in this area are:

- **Supplier Financial Standing**
  - Financial Ratios
  - Debt Ratings
  - Payables
- **Exchange Rates**
- **Labor Rates**
- **Proposed Price**
  - Cost Audits
  - Comparisons of other Offers

Design Risks

Design risks will capture any risk that is introduced by Sikorsky's design process. The major factor here is the maturity of the design. As designs get more and more mature, the number of redesigns and the probability that the aircraft will not fly, as designed, will decrease.

The level of Sikorsky (or other company) competence in building the design will directly affect the ability of the project to stay on schedule. After the project is introduced, there will be modifications and additions to the design. How many of these are anticipated, how many are possible and how many are likely. How will these factors affect the cost and schedule of the project? Another design risk addresses how well the design can deal with quality issues. This will look at how tight the spec limits are for Sikorsky partners and how much above and beyond that Sikorsky can accept when integrating the supplier's part with the rest of the aircraft. Will quality problems set Sikorsky back by a large amount, or are there contingency plans in place? The final design risk involves the transfer of Sikorsky's knowledge of the process to the new partner. The main question is how can you transfer knowledge that may not have been written down or communicated back to the design engineers. For example, on the manufacturing floor, many changes will be made to the operations sheets to make fabrication more efficient. Many of those changes only exist in the operations sheets on the floor. How do you ensure that you don't lose those productivity improvements when the operation is moved? Even more basic a concern is how to ensure that every detail is communicated correctly. Due to culture, geographic or language barriers, the interpretation of some specs may be very different in other regions. The risk drivers here are:

- **Design Maturity**
- **Knowledge Transfer**
    - Language Barriers
    - CAD data Compatibility

Operations Risks

How the partner operates can also contribute considerably to the risk profile of a supplier relationship. The main operations factors identified as risks deal with the upstream supply chain, quality standards at the company, risk in transfer of goods from the supplier to Sikorsky, and the partner's manufacturing capabilities. These factors can be seen as the most direct influences on the supplier's performance, as far as Sikorsky is concerned. For example, financial, design, and business issues may significantly affect the overall company and in-turn effect the goods delivered to Sikorsky, the operations risks, however, focus on the mechanisms by which the supplier creates and provides the goods to Sikorsky.

The upstream supply chain in the operations risks refers mainly to the materials that the supplier purchases. The profile of where, how, and how much is purchased can say a lot about the probability that a supplier will be able to deliver acceptable quality, on time, and within budget. The important factors that were identified with respect to supplier materials purchasing is whether they're able to purchase on the same terms as Sikorsky does, in cases of outsourcing, the supplier's experience with international contracts, and how their credit standing is with respect to their suppliers. Questions are focused on determining how healthy the company is with the materials they are purchasing, how current they are on their accounts payable and finally whether their material cost will be comparable to Sikorsky's or a competitors for creating the same product.

Quality is important in any supplier relationship, but with aircraft the bar is raised even higher as non-conforming product can mean the loss of life. Supplier quality is a result of their efforts into defining quality standard and their ability to deliver reliably at the specified standard. The first portion of the risk analysis focuses on past parts-per-million (PPM) defect rates with this supplier. This data can be taken from previous business with Sikorsky (previous 5 years max), or from business with other customers (via publicly available information). The next area of focus is on how the supplier creates and enforces quality standards. By asking questions about use of quality systems (i.e. Six Sigma[7]) and whether there is a dedicated quality group or person, a measure of the supplier's commitment to quality can be obtained. Finally, the technological sophistication of the supplier's manufacturing equipment is considered.

The supplier's manufacturing capabilities are analyzed from the aspects of lead time, capacity, and previous delivery performance. As is generally the case, a supplier who is pushed to their capacity and lead time limits will most likely show service level issues and late deliveries will ensue. Tied to this is an analysis of previous delivery metrics for the supplier. The intent is to determine whether the supplier has recurring delivery issues.

- **Materials Purchasing**
- **Quality Standards**
- **Shipping Mechanisms**
- **Capabilities**

[7] Various Six Sigma references are available from Motorola at http://www.motorola.com/motorolauniversity.jsp

- Capacity
- Lead Time
- Previous Delivery Metrics

Business Risks

The previous risks have all been factors of the partner and Sikorsky itself. The final area, business risks, more directly address concerns outside the scope of the companies involved. These risks include geo-political and social risks, which hope to address whether political and social issues in the partner country could affect the contract between the two companies. Demand, Competitive and Cannibalization risks attempt to address whether marketing's view of the project is accurate. Is the demand truly what is expected? How certain is the demand? The last area is Licensing Risk. Licenses must be granted by the governments involved to allow the manufacture of this aircraft abroad. Examples would be a Manufacturing License Agreement (MLA) or Technical Assistance Agreement (TAA) per United States International Traffic in Arms (ITAR) regulations. How difficult will it be to obtain and maintain these contracts?

- **Geo-Political Risks**
- **Worker Risks**
  - Unions
  - Strikes
- **Demand Stability**
- **Uncategorized Ratings from Online Database**
- **Licensing**

Each of these risks must be identified and quantified. The process of addressing these risk factors will also open the door to increased information sharing between the supplier and Sikorsky, and hopefully lead to greater supply chain visibility. "The visibility makes the supply chain more transparent and can lead the way for performance improvements." (Lambert and Pohlen, 2001). A small example of this increased visibility in the risks analyses above is for the assessment of the supplier's source of supply. Some problems are, however, inevitable. For these problems, having a diversified supplier portfolio may allow the company to overcome randomly occurring problems in one (or more) suppliers. Local unrest in one country can be diversified away by having secondary suppliers in a different country. A trade-off must be made though.

Many modern customer-supplier relationships have focused on intimate relationships and reducing number of suppliers. There needs to be careful analysis of the relationship and a determination of where along the spectrum you would like to structure the supplier contract, as shown in Figure 1. This is all part of the supplier decision process and the process of identifying and measuring the risks listed above can help aid in the decision.

Supplier Scoring

The third phase of the framework creation, scoring, is the portion where the most insight can be gained immediately. The other phases are intended to spur investigation of one's suppliers, but they don't necessarily provide an instant response of what the supplier's risk factors actually amount to. The scoring portion of the framework is where the user will see the direct influence of project risk factors and how they may affect the outcome.

The process for determining the scoring, as mentioned previously, started with a large amount of research and data gathering. Once suitable data had been gathered, a regression model was created to determine the effect of the risk drivers on various supplier performance measures (the risk effects). A portion of the initial data set had been set aside from the regression process to be used for validation. For validation, the unused data was plugged into the framework and the output was compared against the actual historic performance for those suppliers. Finally, upon successful validation, the model coefficients were used as the weights for scoring in the final version framework.

Data Gathering

For the first portion, a large sampling of data was collected on Sikorsky supplier performance over the last 10 years. The suppliers to include in the study were selected based on the ability to locate the data necessary to fill out the risk framework as if it were the date of negotiations with the supplier (i.e. answer all questions as if it were 1997 and using only data that were available at that time), as well as the ability to measure the performance of that supplier since the evaluation date. In all, data for 50 companies over various time periods through the last ten years were collected. Attention was paid specifically to the distribution of suppliers based on geographic location, size, product type, and other factors to ensure the data accurately represented a full range of the suppliers that Sikorsky uses. The parameters of 50 for the number of suppliers and ten years as the data horizon were selected purely based on what data was available. Data farther back than 1997 was extremely difficult to locate, so therefore 1997 was considered the farthest back that the study would go. The number of suppliers in the study was intended to be greater than 50, but this was once again a function of what data was available and what data was accessible within the timeframe of the project. Though it did not reach the projected population size, the data set was complete enough to conduct a thorough study as shown in later sections.

The data were collected from various sources, both internal and external to Sikorsky. Much of the data was sourced from internal Sikorsky databases, which was the easiest source to get bulk data from once access was granted. Paper and electronic documents were also used for answering a number of questions. Much of this work relied on connecting with the correct people and shuffling through large numbers of documents. The length of time required to gather data for each supplier served as the main limiting factor for the data population size. There is no common data retention standard at Sikorsky for some of the required documents, and though they'd be readily available at the time of supplier evaluation they are difficult to locate in a retrospective study. This is a possible data management issue in and of itself, which will be discussed further in the chapter on future work (Chapter 3). The remainder of the data was collected from internet sources. Multiple performance metrics had been targeted as the outputs of the model, but this list had to be reduced to percentage lateness of deliveries and PPM defect rates. The reason, once again, is that sufficient data did not exist in the population for other resultant performance metrics.

Data analysis to refine scoring

With the data population created, a regression model was created using SAS JmpIn software[8]. However, initial results revealed too few degrees of freedom to create a full model. The root cause of this problem was the fact that the framework essentially has 25 risk questions and the data population has 50 samples. Though the amount of data is technically sufficient, some missing values for certain suppliers pushed the model fit below acceptable levels. The number of questions was subsequently reduced using simple plots of performance vs. response

[8] JMPIn is the reduced price student version. Information on fully licensed JMP software can be found at http://www.jmp.com/software/

for each risk driver question. A qualitative assessment was made of which factors looked to have the largest effect (i.e. using comparative slope among questions). These plots are included as Appendix 1 – Initial Effect Plots (The questions are numbered such that the first letter is the main group **F**inance, **O**perations, **D**esign, **B**usiness. The next number is the question number within the main group and the letter after the number is which part of the question as some questions are multi-part). From these plots, questions F-1a, F-1b, F-1c, F-7, F-9, F-11, D-3, B-1, B-3, B-10, B-11 were removed for Delivery lateness calculations and questions F-1b, F-1c, F-6a, F-6c, F-8, F-13, F-14, O-8, B-9, B-11, B-12 for PPM defect rate calculations. Removing those questions for each response cut the number of factors for the regression to 14 for both Delivery Lateness and PPM defect rates. Factors were cut if their response had possible redundancy with other questions and if the effect (slope) of the factor in the Initial Effect Plot was insufficient to merit including it. Another technique that was necessary to keep the sample size respectable was to split the regression into two parts for each performance factor. The necessity to split the regression was based on the "orthogonal" nature of some of the question responses; there were three questions that had the possibility of being quite illustrative, but they were only available for some of the oldest suppliers, due to the retention policies at Sikorsky. However, these older suppliers had missing responses for some of the questions based on newer Sikorsky databases. Since these questions were believed to be important and possibly illustrative, and they were only three of 25 total questions, the decision was made to do a full model regression with these questions removed so the data set for the regression would not be limited to the few suppliers that had answers to these questions. These questions were then regressed by themselves with respect to the performance factors, to evaluate their possible effect on the outputs. These terms will be referred to as Cost-Price Analysis, or CPA, terms from now on. How these are tied back into the model for framework scoring is described later.

Once the risk drivers with minimal significance (as judged by the effect plots) had been manually removed, a mixed stepwise fit was performed for each performance factor with a significance probability of .25 to enter and .20 to leave. Essentially, this technique starts with no factor effects (risk drivers) in the model, and then adds them one by one if their individual significance probability (based on the test statistic) is below the probability to enter. After each factor is added, the error term for the model is recalculated and thus significance probabilities are recalculated for each factor. As factors are added and significance probabilities change, they are monitored to make sure they do not drop below the probability to leave. If they do, they are removed from the model. This technique is a mixture of forward selection and backward elimination and is offered as a standard feature in SAS JmpIn. The concepts behind these methods are available in statistics literature (Hocking, 1976). The data yielded a model for each performance metric. These are analyzed below.

For each performance metric regression, the statistical printout is included in Appendix 2 – Model Regression Printouts. The results show the key factors that affected the percentage of late deliveries in the gathered data are the financial stress score (which is an indicator from the online database), labor rate trends, exchange rate trends (for international companies), and two other ratings from the online supply chain database, order accuracy and business relations. This model achieved a model significance probability (overall p-value) of .0025 and an R-Square of .68. The actual vs. predicted and residual vs. predicted value plots for this model can be seen in Figure 5.

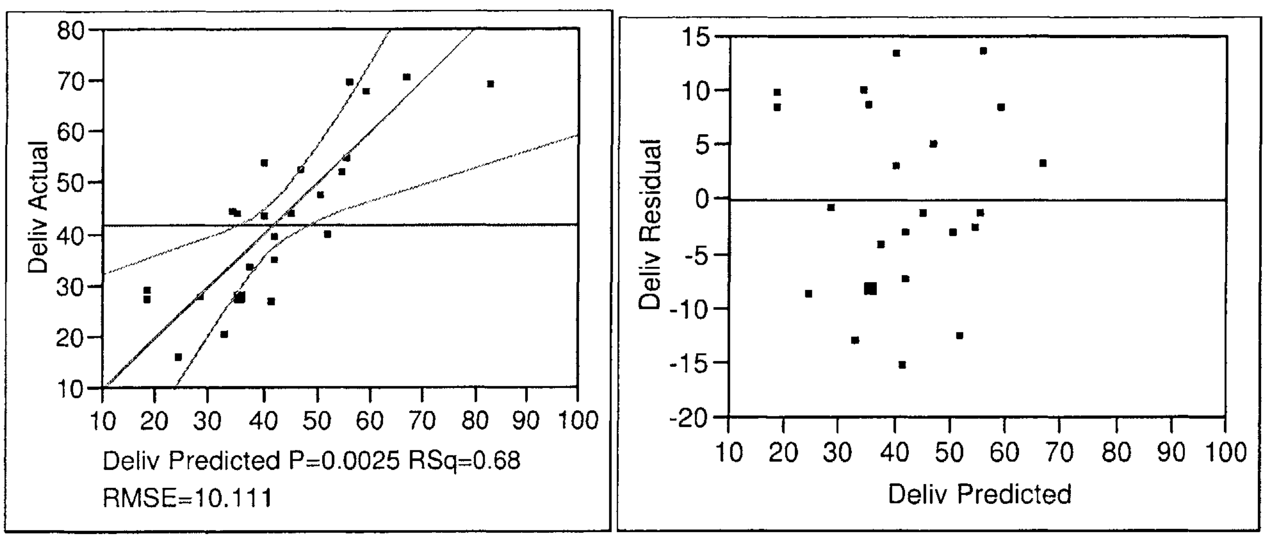

Figure 5 - Delivery Model Fit (in percentage of late deliveries)

In the case of PPM defect rates, the non-CPA factors that matter most are whether the company supplies public financial reports, past quality performance, and a timeliness rating from the online supply chain database. This model achieved an overall p-value of <.001 and an R-Square of .83. The actual vs. predicted and residual vs. predicted value plots for this model can be seen in Figure 6.

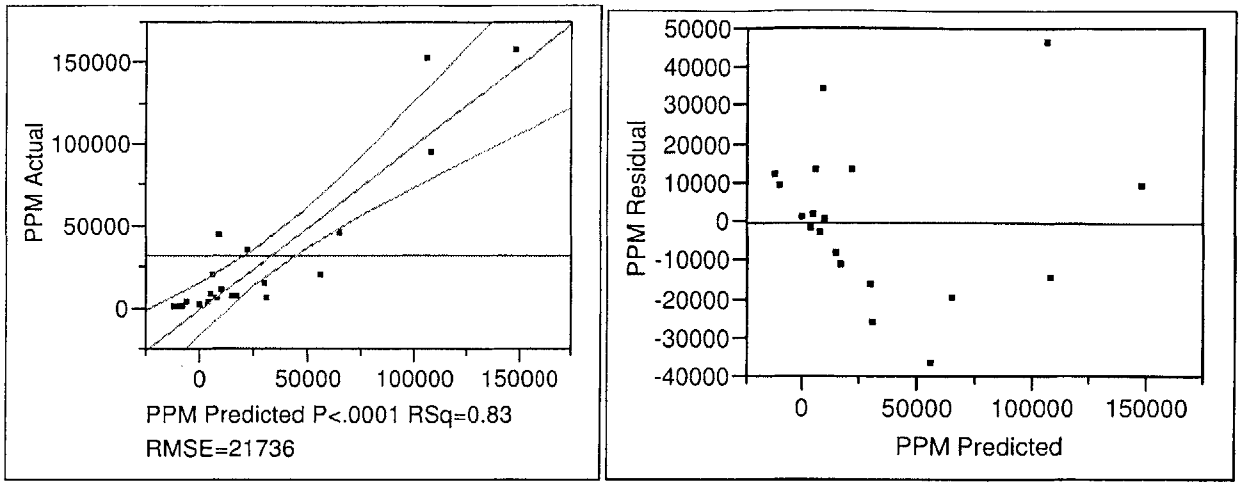

Figure 6 - PPM Model Fit (non-CPA)

Finally, the only performance measure that appeared to have a statistical dependence on the CPA terms was the resulting PPM defect rates. The most important CPA factor to PPM performance was the percentage of product cost from labor (as opposed to materials). The model achieved a p-value of .054 and an R-Square value of .39. Though a statistically significant fit for this factor does exist, it has suspicious qualities. The model used a small number of data points and the residual vs. predicted plot shows an apparent change in variance for different factor levels. This portion of the model should be used sparingly and possibly only serve as a starting point for future studies as its results will not be very accurate if used in the current state. The actual vs. predicted and residual vs. predicted value plots is depicted as Figure 7.

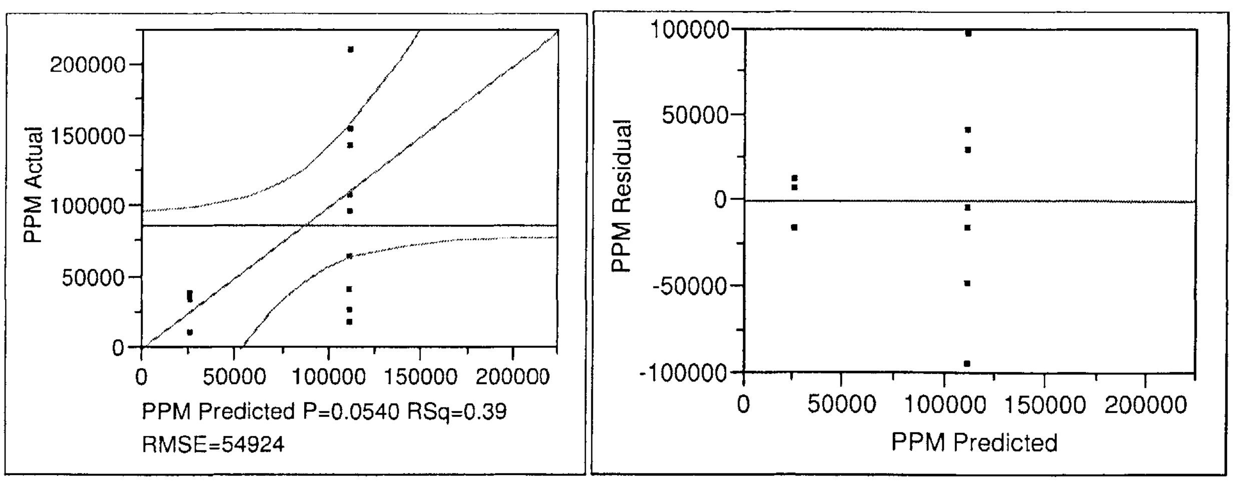

Figure 7 - PPM Model Fit (CPA terms)

A summary of these connections is contained in Figure 8 below. Dashed lines indicate a factor kept after analyzing the plots in Appendix 1 – Initial Effect Plots. Solid lines indicate statistically significant effects as determined by the regression model. Only questions from the framework for which data was obtained are included in the summary figure.

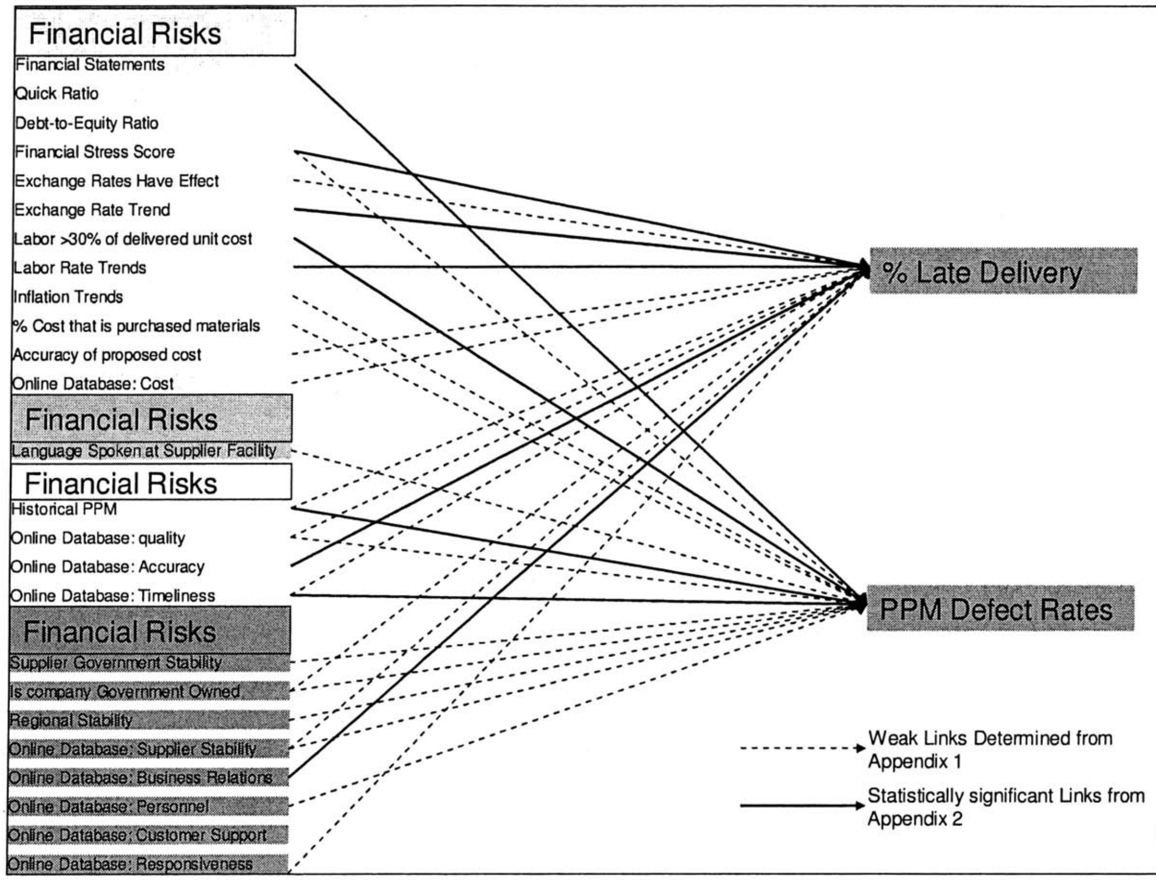

Figure 8 - Risk Driver/Effect Connection Summary

Validation of scoring

To validate the models that were created from the data, the excluded samples were then used to calculate predicted values with the models and these values were compared with the actual performance, as collected. Five samples were excluded from the original data set of 50 to compute the non-CPA models. The CPA based models posed an even tighter restriction on validation factors as CPA data was only available for 15 of the 50 suppliers. Therefore the number of validation factors was reduced to two. In both cases the decision was made to focus the data on model creation, rather than validation. The plans had originally set out for a larger number of validation factors, but the limits to data available forced the decision to reduce the number of samples. A thorough explanation of the reasons that drove these decisions is included in later sections.

Predicted and actual plots for the validation points have been included below as Figure 9 and Figure 10. The plots show a correlation in slope for the models. As a predictive system, it can be seen that the predicted values differ from the actual values. However, as a relative scoring mechanism, slope is what matters most and will drive the scoring of the model.

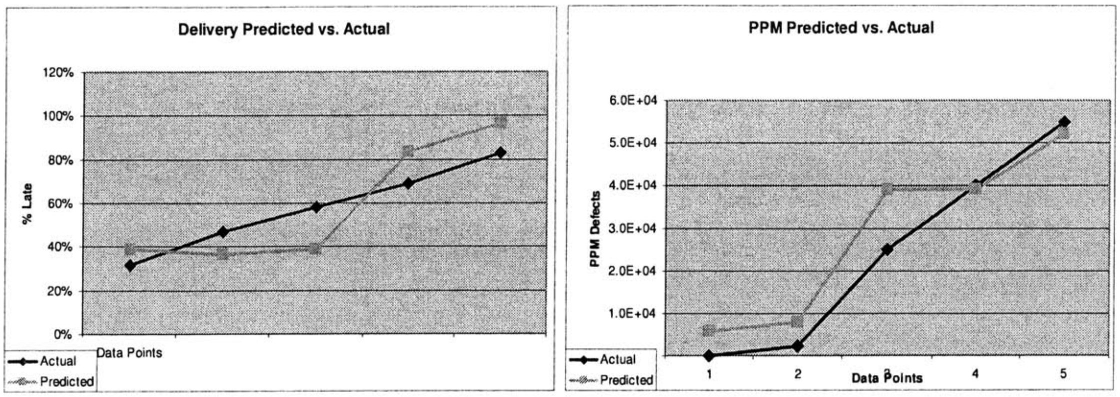

Figure 9 - Predicted vs. Actual for Delivery and PPM, non-CPA terms

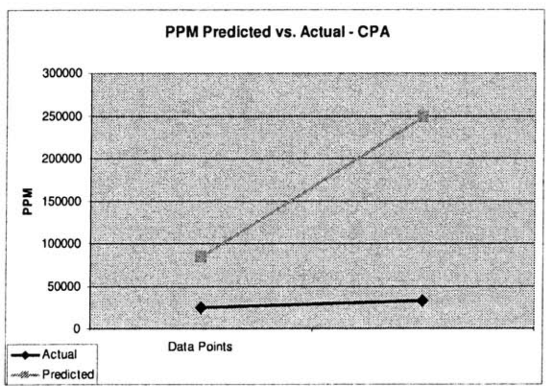

Figure 10 - Actual vs. Predicted for PPM CPA terms

Scoring Discussion

The ultimate application of the regression models is to use model coefficients in the framework as the scoring weights for the risk driver questions. To properly compute weights, the full range of response to each risk driver was compared to the total range of effect on the performance factor, as predicted by the model. For example, in the case of late delivery, given the model coefficients in Table 3, the weight for the Financial Stress Score (F-5) question is approximately 12%. The equation used to compute this weight is presented as Equation 1. To use the equation, the coefficient for a question is the value in the "Estimate" column of Table 3, the x_{max} is the maximum value that was inputted into the model for question x, and x_{min} is the minimum value that was inputted into the model for question x. For most questions in the study, answers were rated on a scale of 1-10, so the maximum value is 10 and the minimum is 1. An exception to the "Range" equation exists for terms with the x{y-z} notation in model output (i.e. F-6c and F-8 in Table 3). These terms are not continuous variables in the range of 1 to 10, they instead use discrete values between 1 and 10. The x_{max} and x_{min} values to use in the "Range" equation for these factors are 1 and -1 respectively.

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	203.88011	41.47801	4.92	0.0002
F-5	-4.655456	1.401253	-3.32	0.0043
F-6c{5.5-3.25&1}	-7.971682	2.871652	-2.78	0.0135
F-6c{3.25-1}	-12.54417	4.562795	-2.75	0.0143
F-8{7.75&5.5-10}	-6.717297	2.989993	-2.25	0.0391
O-8	-58.2893	13.84867	-4.21	0.0007
B-9	42.225925	13.62475	3.10	0.0069

Table 3 - Late Delivery Coefficients

$$Weight(F5) = \frac{Range(F5)}{Range(F5) + Range(F6c) + Range(F8) + Range(O8) + Range(B9)}$$

$$Range(x) = \left|coefficient * (x_{max} - x_{min})\right|$$

Equation 1 - Model Weight Calculation

Using this approach, additional care must be taken regarding limiting of certain input factors. Some factors, like those from the online supply chain database, display scores on a scale from 1-10, but scores below 7 are extremely rare (in our data population for O-8 and B-9, the range for these drivers was 7.5-9.7). Therefore, the weights were calibrated using a range for O-8 and B-9 range of 7-10. All values below 7, should they ever occur, will be clamped to a minimum value of 7. Given the data population, this is a fair assumption, since the model was created with no data for values below 7 and thus these serve as somewhat unknowns as far as the model is concerned. However, as the model is updated periodically, these bounds should be rechecked to ensure they still represent valid assumptions. In this same fashion, weights were computed for each relevant risk driver and then added into the framework.

The framework creates a risk score for percentage late delivery and PPM separately. These two scores are then displayed independently and averaged for the overall risk score.

In the analysis of the validation points of the model, the statement was made that the relative slope of the predicted values as it compares with the relative slope of the actual values is more important than the exact matching of the predicted values to the actual values. The intention of this statement is to stress that the tool is a relative evaluation tool rather than an absolute evaluation tool; i.e. the goal of the framework is not to predict that company A will have, for instance, 31% late deliveries and company B will have 65% late deliveries but rather to provide guidance that company B will most likely have a higher percentage of late deliveries and thus poses a higher level of risk. The fact has not been ignored that a tighter fit of predicted versus actual values would enrich the comparison of the two companies, by providing a more precise measure of how much higher company B's percentage of late deliveries will be. The argument against this notion is that the higher accuracy model may create a false sense of trust in the model and that supplier performance is still a pseudo-random process and a more precise model may not improve the overall accuracy of the resulting analysis.

Finally, it is worth mentioning mental models that could support the results of the models. For percentage of late deliveries, it was stated earlier that the important factors were financial stress score, labor rate trends, exchange rate trends, and two more factors from the online supply chain database. Factors that display an intuitive response are exchange rates and the supply chain database metric for business relations. The exchange rate correlation shows that when the U.S. dollar is performing very poorly with respect to the supplier's currency, late deliveries rise. As the U.S. dollar gets closer to tracking the supplier's currency, late deliveries drop. The intuitive explanation here could be related to the fact that many of Sikorsky's contracts are paid in U.S. dollars. If the U.S. dollar is quickly devaluing with respect to the supplier's currency, they may have less incentive to rush delivery and get paid in an extremely weak U.S. dollar. However, as the U.S. dollar gets closer to tracking their currency, the effect of the successful foreign economy and the close tracking of the U.S. dollar create the incentives to deliver on time. At the opposite end of the spectrum, the model could be indicating that with a quickly valuing U.S. dollar, deliveries seem to not be affected. The logic here can be related to a valuable dollar and external problems with the business climate in the supplier's country causing the supplier's currency to devalue vs. the U.S. dollar. These factors could offset, thus prompting no overall effect on deliveries. Another intuitive connection with deliveries is the connection between the business relations rating and deliveries. It would be easy to conclude that a supplier that delivers on-time is more likely to have friendly dealings with their customer. In the PPM regression model, most of the non-CPA factors can be intuitively explained as well. The factors are previous quality metrics and the online supply chain database rating for delivery/timeliness.

The mental model supporting the connection between poor quality in the past and resulting quality performance in the future is that those with poor quality will rarely make large exceptional quality improvements and thus deliver low quality products in subsequent contracts. This mental model is backed up in the data. If a company appears to have had poor quality performance before working with Sikorsky or in previous work with Sikorsky a reasonable assumption is that these quality problems have not just gone away. In terms of the delivery/timeliness rating, the data shows that a high rating for delivery/timeliness results in higher quality problems; the assumption here being that a company focusing purely on getting product out the door may be more likely to overlook quality issues.

In contrast to the factors presented in the previous paragraph, some of the connections between risk drivers and performance are not entirely obvious. However, this is not to say a possible cause can not be imagined. These factors point to possible areas of continued exploration and even a new mental model of how these risk drivers behave. One example factor is the connection between a supplier that provides annual reports and PPM defect rates. Original analysis of these suppliers for this project focused on the data in the financial reports; financial ratios were tested for correlation with resulting performance. However, no connection exists. The connection, however, is purely between the act of providing reports and the defect rates. When looking at companies that provide annual reports, they are generally the larger public companies. When perceived from this angle, the connection can drawn that a larger customer, focused on more diverse customers may have a larger quality problem than a small local company who's largest contract is Sikorsky aircraft. In this context it is the opposite of the intuition that a large sophisticated company should have better quality product than the basic local company. However, the maturity of the company has not been considered. Just the fact that they are publicly traded and provide annual reports does not mean they are a mature established company. This example highlights the need for future studies to include further metrics, such as company headcount, output, maturity, or customer base as new risk drivers. Another example where the obvious mental model may be broken is that the regression shows no strong connection between the online supply chain database score for Delivery/Timeliness and the supplier's resulting delivery performance. One would expect these two values to be very closely related. However, it may be simply illustrating that past delivery performance does not affect future delivery performance. This is the opposite of the link shown between historic quality performance and resulting quality performance, where historic quality problems persist.

Chapter 3: Conclusions and Future Implications

The scope of this project was focused on the creation and tuning of a framework for supplier evaluation, but the effectiveness of this work as a supplier evaluation tool depends on continued effort with the framework. Only with continued effort and diligence will the project reach its full potential. Having discussed the motivation and actual creation of the framework, this chapter opens with the next steps required for the project to be successful. The key areas of future work are the implementation plan, data retention measures, and framework improvement plan. The chapter then closes with the broad conclusions drawn from the previous sections of this work.

Implementation Plan

First and foremost the framework needs to find its way into the hands of the buyers in the Sikorsky Supply Management group. The buyers will be both the greatest users and drivers for improvement. It will be crucial to introduce the program correctly and sell it as a tool to help the buyers and not just another useless management requirement. One way to achieve user buy-in with such a tool is to start with a pilot study. In this way, use of the framework can be focused on a few buyers that may be more likely to adopt such a tool. Also, the pilot study may serve as a way to gain further employee feedback on the framework, so the users can "make it their own". Another key to getting the framework adopted as a lasting tool in the company is that there must be a significant value proposition to adopting it. One possible value-proposition to help sell the framework is to position it as an insurance mechanism in the event of poor supplier performance. For example, in the current state buyers and managers each evaluate suppliers in their own way and are generally accountable for ensuring suppliers relationships are successful. However, if a standard tool is used by everyone, risky suppliers will be pointed out early, regardless of how risk prone/averse a buyer is. Also, in the event that a supplier performs poorly despite a good rating from the framework, the buyer has some leverage and can prove their due diligence by having used the framework; poor supplier performance can be seen as the effect of an anomaly rather than poor preparation by the buyer. Finally, the message has to be relayed that the results of the tool are important to management. If the risk scores are ignored or disregarded in many cases, the users will stop using the tool as it will be perceived as unimportant. This will take commitment from both parties involved.

Data Retention Measures

As mentioned earlier, a major hurdle to the success of this initiative is the differing data retention policies used throughout the company. The first change that needs to occur is a commitment within management to standardize data collection at Sikorsky. This can be achieved through mandates of common retention systems and policies. As with most corporate change initiatives, it is important that there is buy-in from all parties involved and that the change is not forced from above. However, if all users understand the goals and benefits of better retention policies, a change can truly be made.

As the user base of the framework grows, a secondary benefit is that it will formalize the collection of common data throughout the group. In effect, the framework will serve as a method for aggregating pertinent data on a supplier into a single database that can be retained on its own schedule, regardless of what the other parts of the company decide. This can serve as a robust data source for refinements of the model as well as by other parts of the company for information about Sikorsky's supply base. An audit of the questions within the framework should be conducted and the data necessary to answer each question should be included in any new data retention system.

Another aspect of the data retention will be the addition of new questions and data sources to the analysis over time. As users start to see new risk factors emerge in supplier relationships, these factors can be added to the framework and tracked. When the model is updated next, the newly tracked data can be integrated into a subsequent model regressions rather than having to dig up data in retrospect that may not be available anymore, which was a recurring problem in this study.

Refinement Plan

The natural next step, once the framework is widely used and more data is collected, is that the scoring will be refined over time. As discussed earlier, the amount of available data limited the amount of analysis possible in this study. More formalized data collection through the supply management department will allow regular updates of the model scoring. These updates will show the effects of new supplier trends as well as refine the effects from previous model studies, like this one.

On a set schedule, a select group of managers and buyers will need to gather and review the model. This review will focus first on the questions within the questionnaire. Over time, some questions may be proven useless to the analysis, while new questions may be added to contribute to ease of use or effectiveness of the data collected. After the review of the questions, the scoring weights should be updated based on the newly collected data. Off-the-shelf statistics tools can be used to allow the model to follow new supplier trends as new data is collected.

There are also opportunities to improve the way the framework develops a risk score. Beyond simply displaying a single value for the risk score, the model should also display a measure of the possible range or variance in risk expected. Figure 7 is an example where variance changes significantly based on the model inputs. Though the initial decision was made to use the mean values for the risk score, for simplicity, future refinements should capture the effect of the framework questions on the variance of the expected performance.

Conclusions

The project started with an idea about the inadequacy of current supplier evaluation methods in use at Sikorsky and has ended with a risk evaluation framework and a plan for the future. The Risk Evaluation Framework encapsulates the knowledge gathered from multiple supply chain professionals, both at Sikorsky and external to the company, as well as data and metrics from diverse parts of Sikorsky and external publicly available data. This data and knowledge has been used to set the format of the framework, tune the questions within the framework and draw connections between various risk factors and ultimate supplier performance. In addition to giving the user "answers" about a supplier, the framework's main purpose is to get the user to ask questions they may not have asked otherwise, which is where the true learning will take place. As mentioned, the Framework will have to be updated and refined to provide valid results over time; it's not the output of the model that provides the largest value, however, it is the process that will hopefully drive the Supply Chain professionals at Sikorsky to ask the right questions and make a focused deep dive into analyzing suppliers. This is not to say that the scoring mechanism is not adding value. The learning also continues in providing data driven scoring for a supplier; not due to getting a single number result (which does have its uses), but more importantly in getting the user to think about the relationships and why a risk driver may cause performance to suffer in a supplier. It also serves as a proof of concept that one can see a correlation between seemingly unrelated aspects of a supplier and resulting performance. These correlations can then be used to enhance the supplier relationship.

Chapter 4: Organizational Analysis

To assess the ability of the project to be effective and also develop a strategy for completing the project in a timely fashion, a three lens analysis was used. To address the project's overall effectiveness each lens was used to determine what the employees at Sikorsky really respond to, and in turn guided the ways in which the project was crafted. Taking into account what all three lenses revealed about the project's implications, it allowed the project to be formulated so it is helpful to the users rather than a hindrance. For the latter issue of being able to gather the data needed, the lenses were used as a guide on whom to approach within the company and how to approach them to convey that the data will ultimately help the company. The analysis starts with the strategic design lens, moves on to the political lens, and then finishes with the cultural lens.

Strategic Design Lens

The strategic design lens focuses on the structures of the groups and policies within the company and the ways in which those structures and policies are linked. In the example of international procurement, it is an offshoot of the overall supply management group, tasked with focusing on international suppliers. The linkages between the overall supply management group and the international group are both in proximity, as both groups are located next to each other, but also through processes. Both groups are tasked with using the same systems and procedures. There is even some overlap between the members of the two groups on day-to-day work. A hierarchy is set up such that the supply management groups as well as a strategic sourcing group all report to the same person to facilitate coordination and consolidation of strategic sourcing resources.

The international procurement group was created to initiate and manage all international supplier contracts for Sikorsky. The group handles relationships and researches regions for suitable international suppliers that offer quality parts at as low a rate as possible. In addition this group is required to find international suppliers to satisfy offset requirements placed on certain projects. The macro challenge that the project addresses is the need to have standardized measures of supplier risk, to avoid making costly mistakes when evaluating new suppliers. This framework allows the user to be nimble in signing on new suppliers, while still monitoring the risks involved. It will provide a more concrete screening mechanism than anything in use today. The project addresses the day to day needs of the group and falls squarely within the strategic tasks of international procurement. A more suitable resting place is probably in strategic sourcing, but as a tool created among the people using it, it may catch on more quickly in the group that created it. However, the international procurement group is small and for the project to have a larger effect, as hoped, the effect of the framework on the larger supply management organization must be mapped out as well.

Overall a micro challenge within Supply Management will exist in transferring the framework beyond international procurement. Though the groups have been set up to strategically work together, many of the linkages between international procurement and the rest of Supply Management are not there on a day to day basis. Many of the other groups within Supply Management have standard work practices and hierarchy set up specifically to allow information sharing and easy access. However, the manager of international procurement has his own streamlined processes within the system and sometimes avoids the standard measures. To overcome the lacking linkages between groups, hierarchical design of the larger group can be used to sell the project to the VP in charge of the group and have it sent to the surrounding groups from above.

When it comes time to implement, one must be aware of both the structural mechanisms used in both the international procurement group and the remaining supply management groups. As long as constructs and methods that are acceptable to both are used, initiatives will avoid getting road blocked by the structure. However, Sikorsky is a very hierarchical company, so support from the top is also a useful mechanism for getting ideas rolled out within the groups.

Political Lens

The political lens is focused on the power within Sikorsky and how that power is used to accomplish tasks within the company. Though the hierarchical design described above is a large source of power within the company, personal relationships can wield just as much power. With Sikorsky's large percentage of senior workers, much gets done through personal contact and purely having contacts in other departments. Many employees have worked in various parts of the company, over the years, and have formed relationships in all of those departments. Anecdotal evidence has shown that when attempting to retrieve data or get help within a group, just approaching the right person and asking may not get the job done. As many of the employees are extremely busy, they must pick and choose what gets addressed first; a stranger approaching with a request will not be on top of the list. However, when approached by a friend or a personal contact, most people will easily make time to help out. For those not as senior in the company it is crucial to develop contacts with those more senior and tap into those networks for help. Friendship and rank both yield power in the company and tapping into either is necessary to survive.

In the context of this project, it was important to ally with those in the company that have important contacts and are willing to help. Beyond that, it is important to properly convey the goals of work and who the work is being done for. In many cases, simply mentioning that the work is being done for the benefit of a friend can help open doors that would otherwise be shut. These power systems create two main paths for influencing: use the hierarchy and have help requested from above, or use personal contacts to navigate the company.

Cultural Lens

To discuss the cultural lens, it will be effective to start with the three structural beams for leverage at Sikorsky, as described in "True Change" (Klein, 2006). Sikorsky appears to favor one side of each beam fairly heavily. On the legitimacy beam, Sikorsky favors the "Experience Based" side over "Technocratic". In the basis for relationships, the hierarchical side is favored heavily, but as mentioned in the last section, examples of lateral relationships in Sikorsky do exist and are quite strong. It is all a matter of a person's years experience at Sikorsky and the personal relationships they've developed. Finally, on the basis for support, Sikorsky appears to be largely authoritarian. Each of these will be discussed in further detail.

It's very apparent from the first day of working how much Sikorsky values age and seniority. The first example is when you park your car. At a facility employing 9000+, at least half of the parking spots (and all of the closest ones) are reserved for those with higher pay grades and larger numbers of years with the company. Another example can be seen in the large number of Sikorsky retirees that are brought back as contractors. Even the badge you wear at Sikorsky bears special symbols for people that have many years of experience. The vast majority of management and persons in positions of power at Sikorsky that I have met have many years of experience. There doesn't appear to be a "fast track", for young, savvy recruits; like the military, you must earn your stripes before promotion. Though recent changes in these policies due to new management can be seen, Sikorsky still heavily favors those who are older and have more experience. Though these examples don't necessarily prove that Sikorsky does not have technocratic culture, they attempt to portray some of the symbols that Sikorsky uses to reward people for their age and number of years with the company.

As mentioned for relationships, Sikorsky leans toward a hierarchical culture. As is the case in the international procurement group, your influence only extends as far as the group you belong to. When the time comes to spread the risk management framework outside of the international procurement group, hierarchical levers will have to be pulled. To do this, a person higher up in the hierarchy must support the work and drive the implementation from above. An example of having to use the hierarchical lever occurred with an informal survey I distributed for the project. I E-mailed a superior for some ideas on people that may help in the survey. Rather than just giving me names and telling me the people that would help, he sent me a response to my request with the names of the people that would help and carbon copied each of the people on the message. In this way, he was telling them to help me. If this request had not come directly from him, I doubt I would have gotten this help. There have also been examples, however, of the effect of lateral connections within the company. I was lucky enough to end up in the same group as an MIT SDM alumnus. This person served as an outsider-insider (Klein, 2004) and helped me make the connections needed to deliver my ideas to key people. Due to his many years of experience, he has contacts in almost every corner of the building, yet he attended MIT recently, so he is able to understand my position. This person has allowed me to bypass the hierarchy in some ways and learn from people that I may have not met. In the long run though, I feel that many of these contacts will discuss work and offer informal advice, but when the time comes that I ask for them to commit some time to helping my project, I may need a push from above rather than a friendly relationship to really get them to take time out of their schedules.

Finally, on the basis for support Sikorsky is very authoritarian. Much of this is built into the culture, but I feel another cause is a fire-fighting mentality that embodies purchasing at Sikorsky. The group is exceptionally good at putting out these fires and thus focuses on that type of work. Many people are so busy that they can not help out unless they are authorized by a person of authority. This will pose a challenge, as discussed, when attempting to roll out the framework to other people in Supply Management. However, once the tool is in their hands, there may be inroads to bypass the authoritarian tendencies to improve the tool and make their job easier. It appears that for first contact with a topic, it must have management backing, but for the workers to improve something and make it their own, they appear to be more receptive to helping.

Three Lens Conclusion

Sikorsky is a large company with very distinct norms. To be effective within the company it is important to learn and follow the company norms as many of employees operate on close personal relationships. After the three lens analysis it can be seen that the most dominant lenses of the analysis are the political and cultural lenses. These two lenses appear to be very closely tied and the reason for this is the military-like culture at Sikorsky. Many of the past and current employees at Sikorsky have backgrounds in the military and Sikorsky's largest sales are military products. An anecdotal example of this was on a tour though the plant one day. While walking through the plant a friend asked me if I'd been into the hangar. I responded by asking, "The commercial hangar?" To that, my friend responded "No, the military hangar". Another long-time Sikorsky employee added "The REAL hangar". The focus on and history in the military has guided management and structural decisions within Sikorsky. It appears that the Strategic Design of policies here was chosen to support the strong culture. The political power feeds directly off of the cultural aspects as well. Many levels of authoritarian hierarchy are used to create an environment and power system that is comfortable to many here, an environment like the military.

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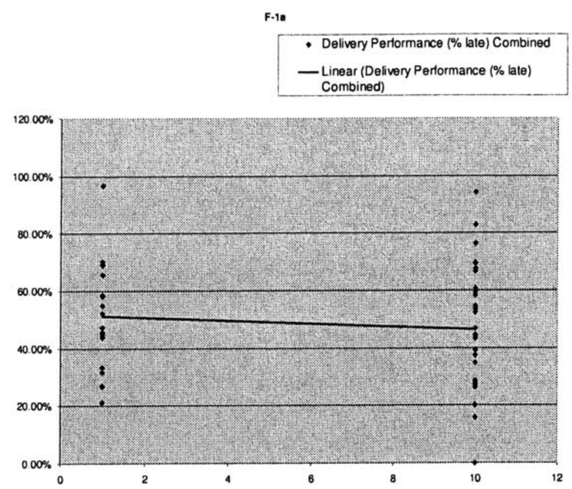
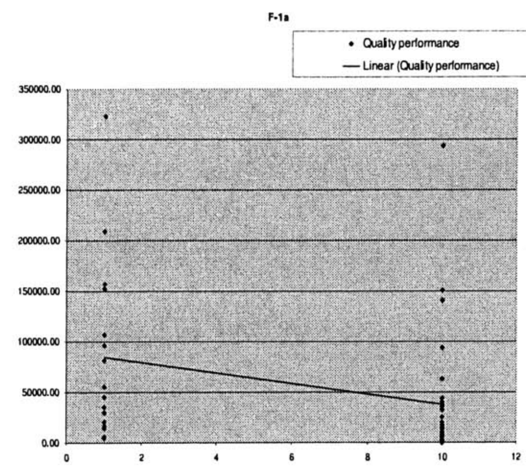
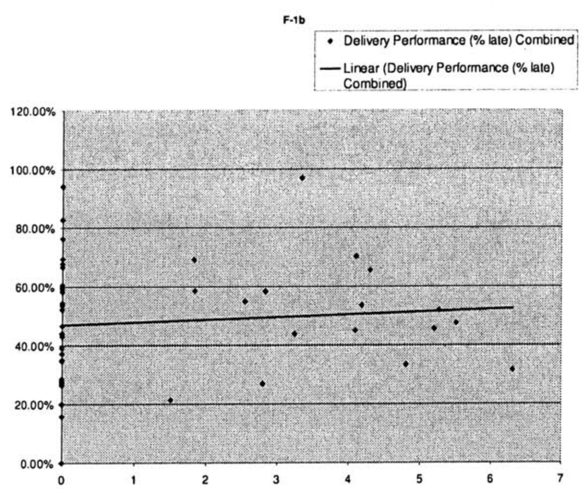
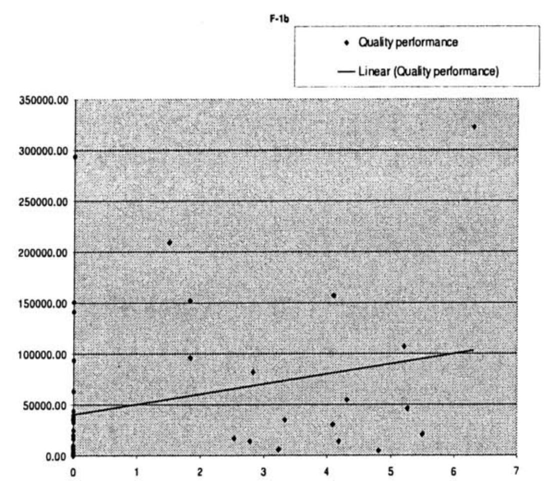
Appendices

Appendix 1 – Initial Effect Plots









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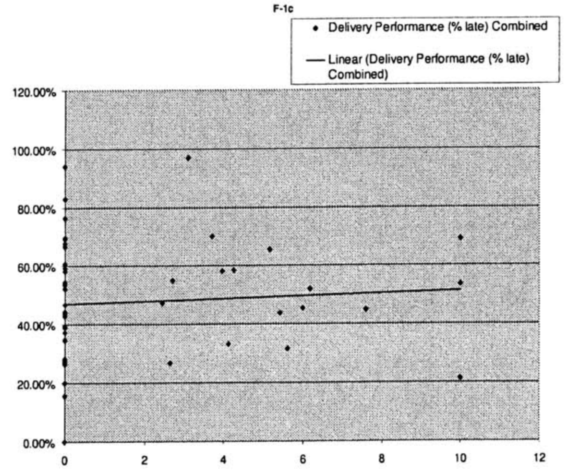

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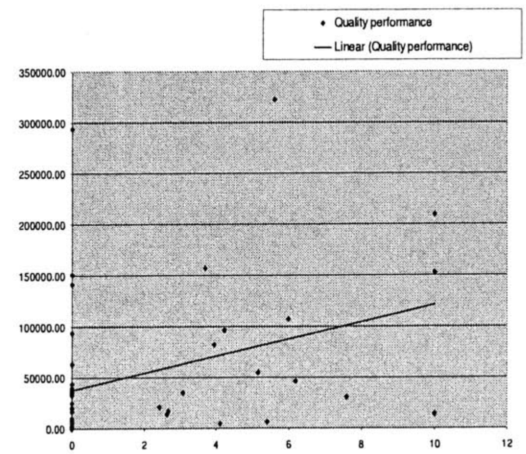

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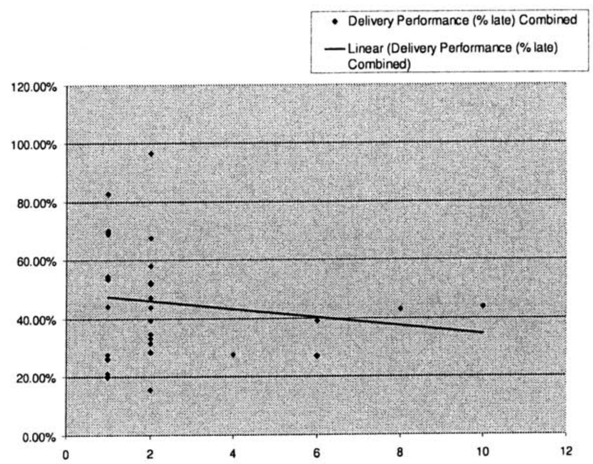

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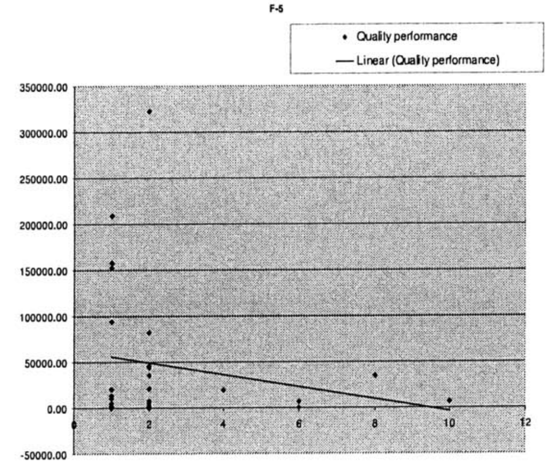

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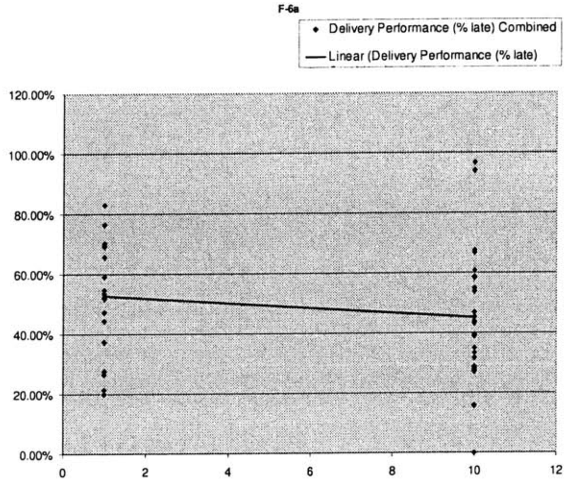

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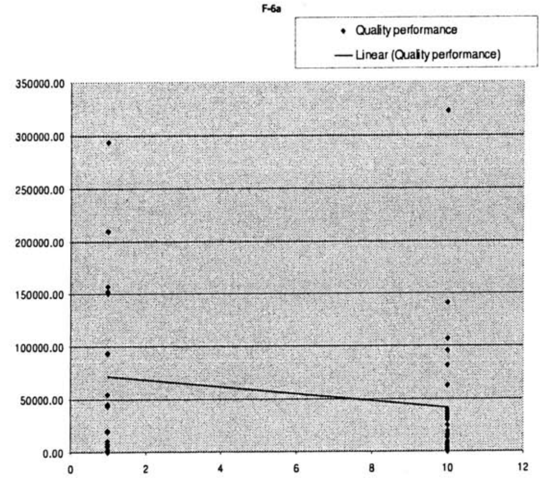

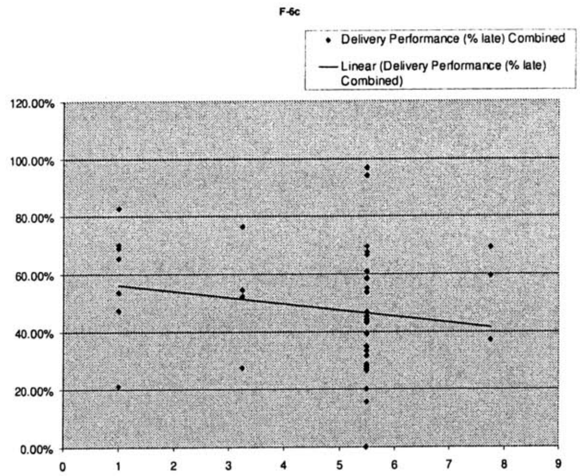
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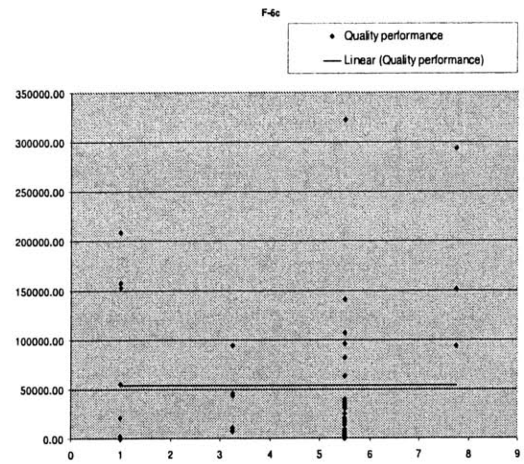
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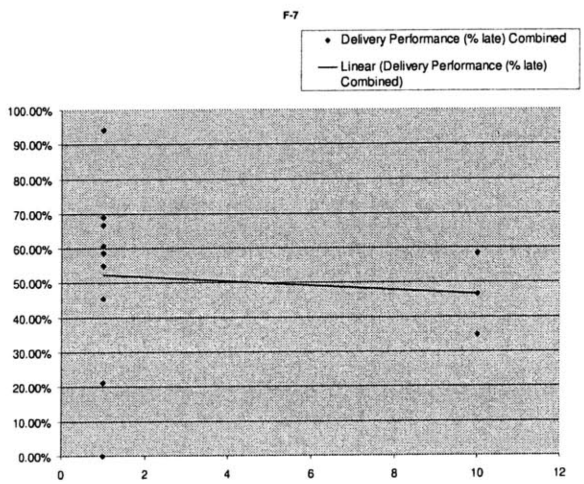
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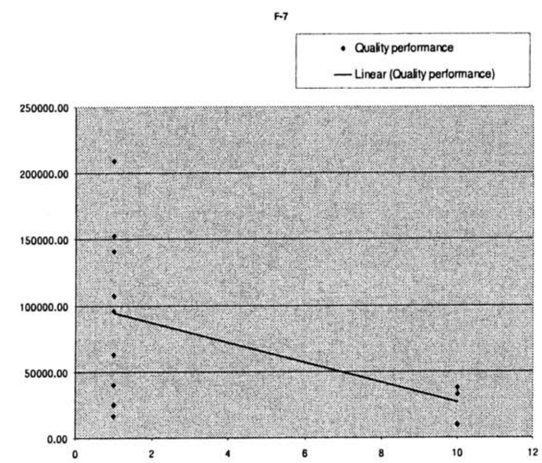
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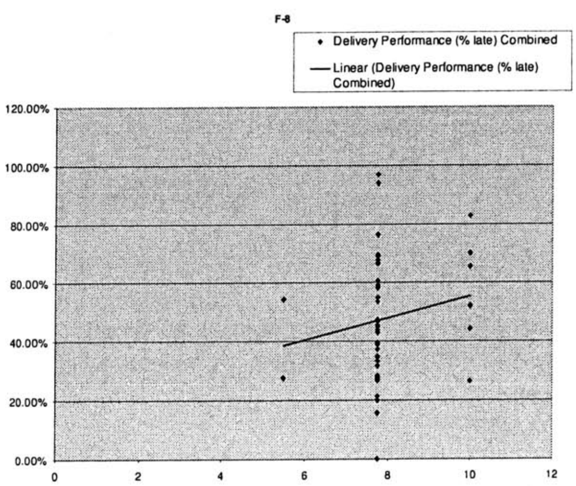
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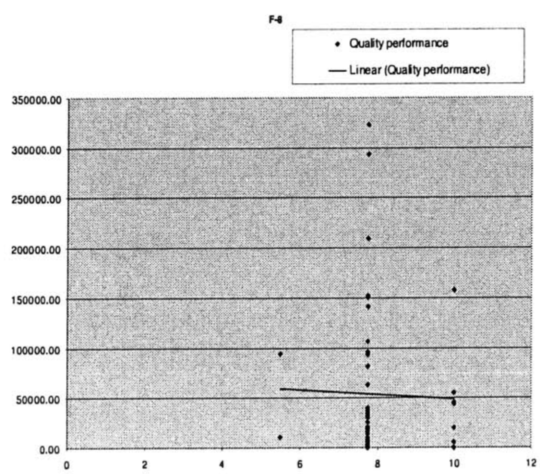
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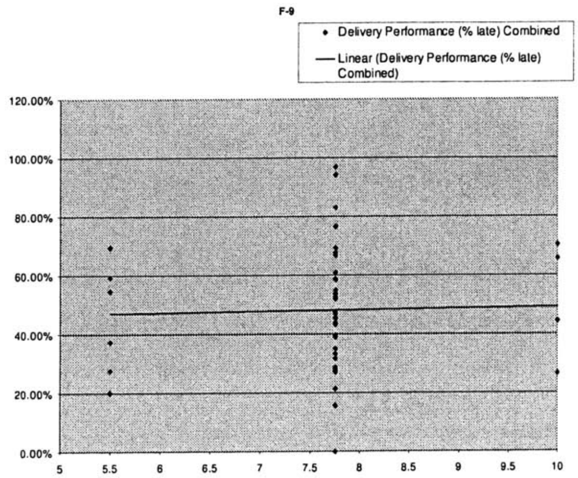
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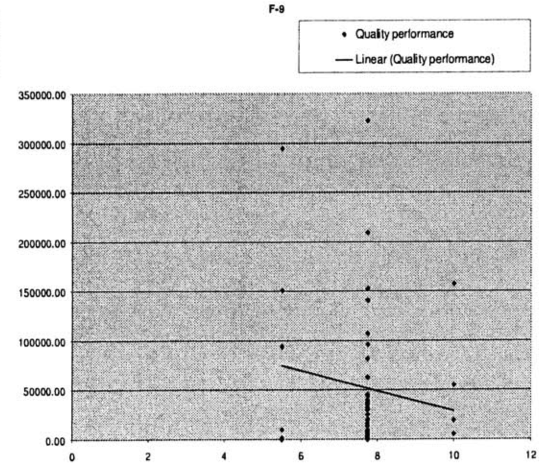
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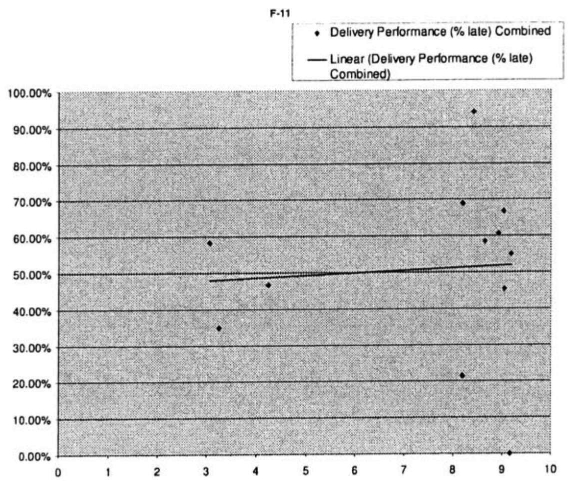
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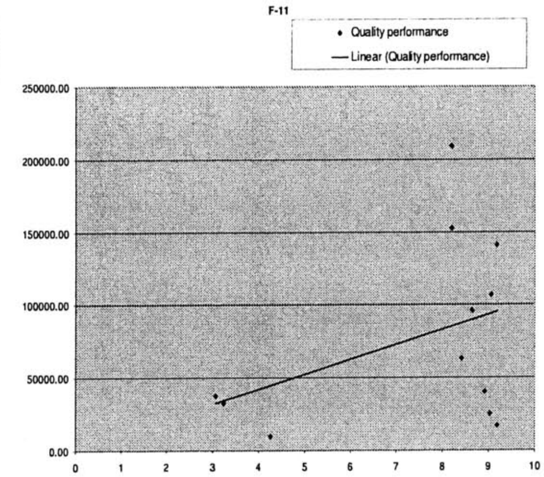
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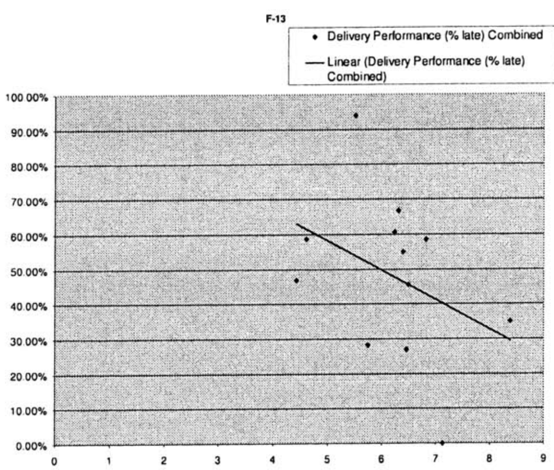
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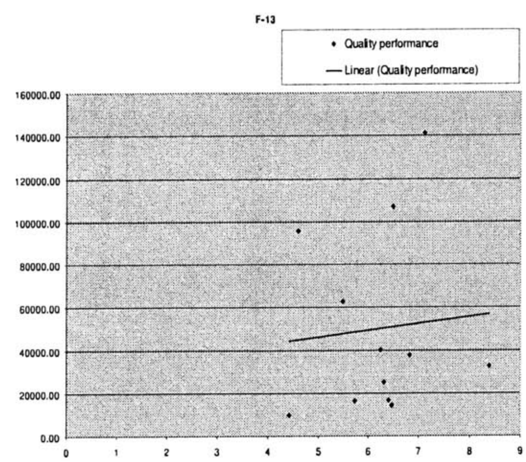
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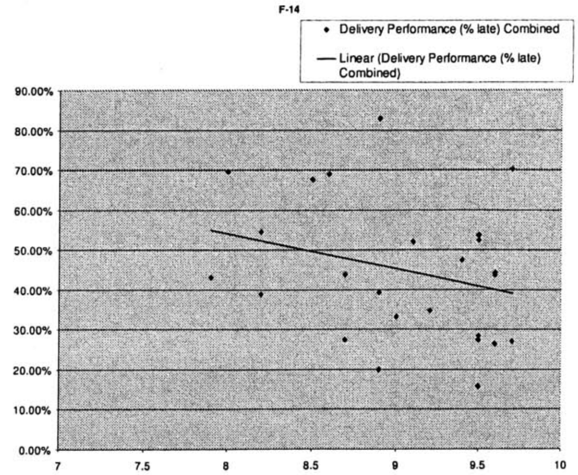
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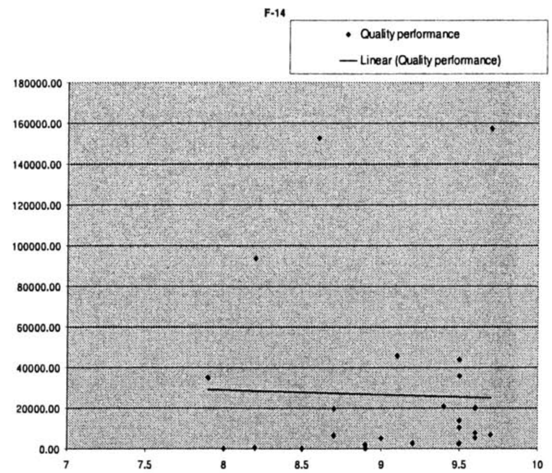
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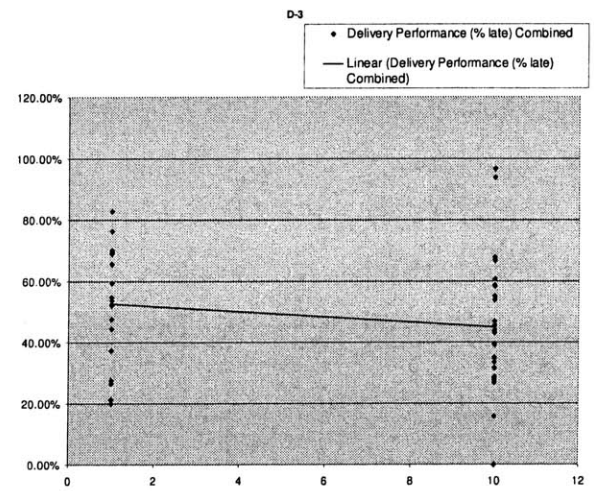
D-3
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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100.00%
80.00%
60.00%
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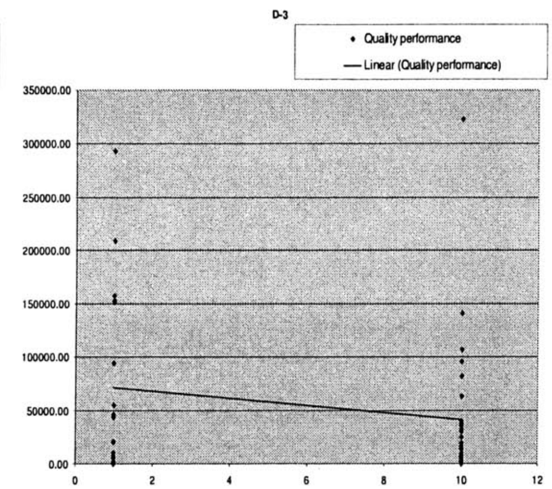
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Linear (Quality performance)
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200000.00
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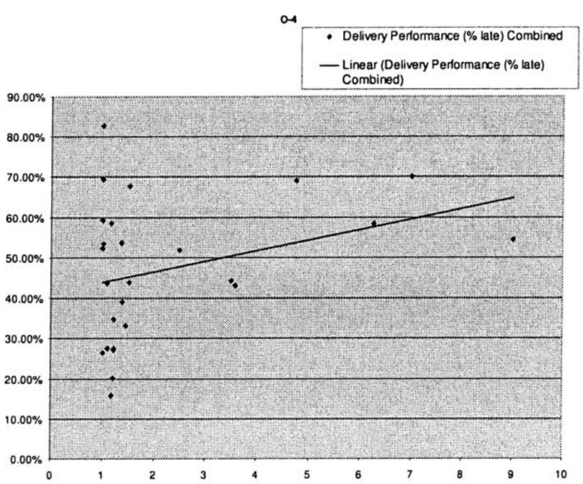
O-4
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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50.00%
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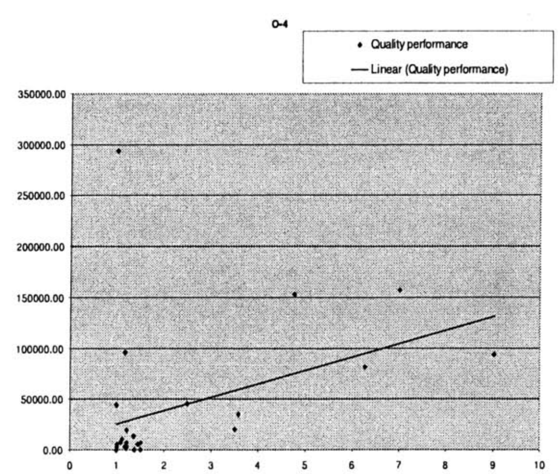
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Linear (Quality performance)
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250000.00
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150000.00
100000.00
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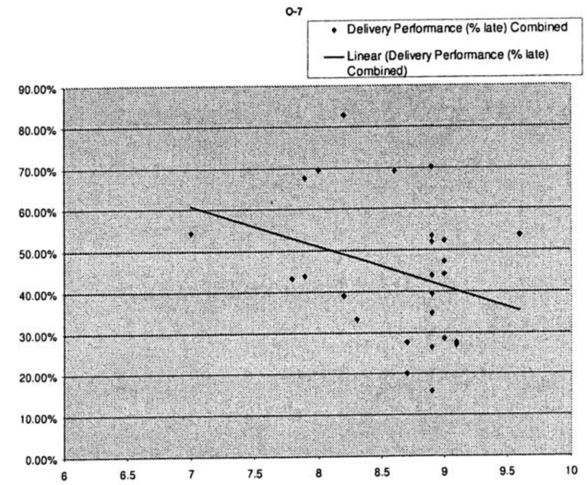
O-7
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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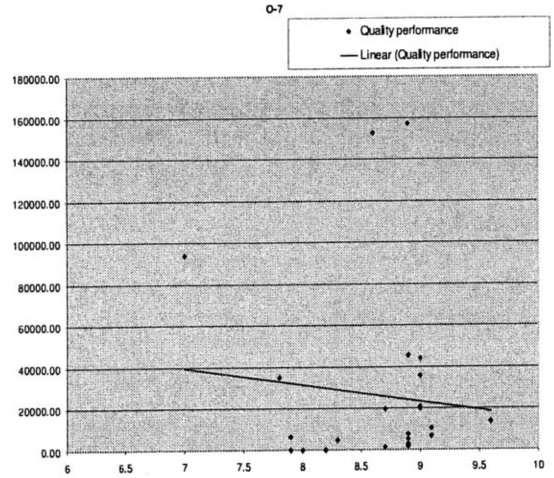
O-7
Quality performance
Linear (Quality performance)
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120000.00
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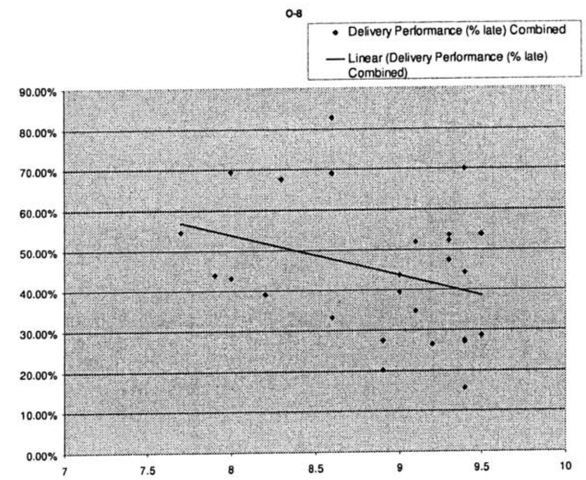
O-8
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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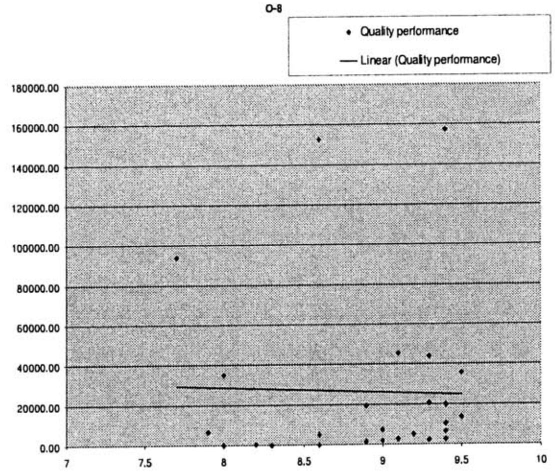
O-8
Quality performance
Linear (Quality performance)
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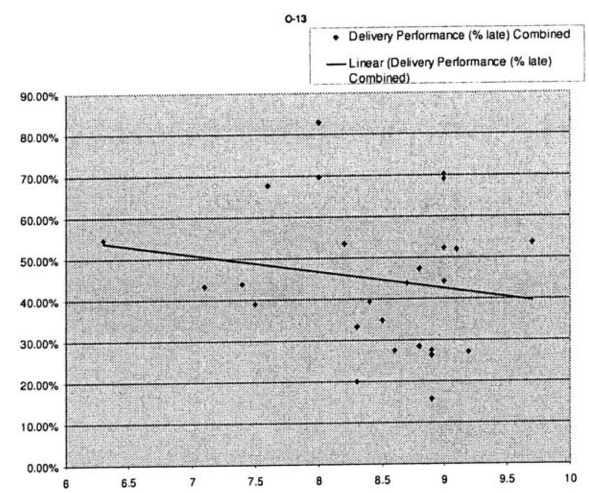
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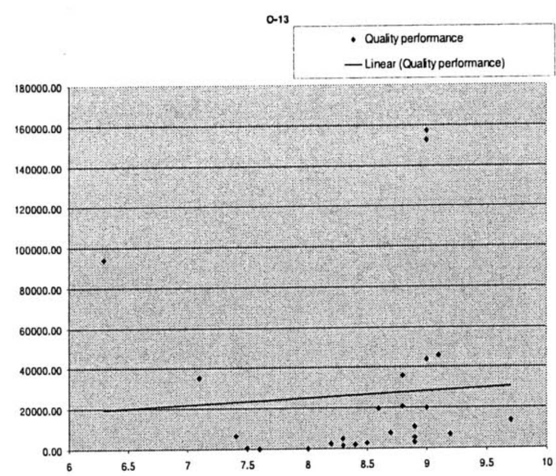
O-13
Quality performance
Linear (Quality performance)
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100000.00
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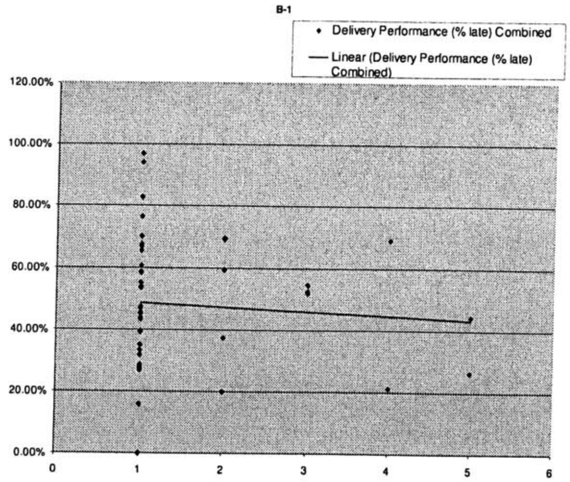
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Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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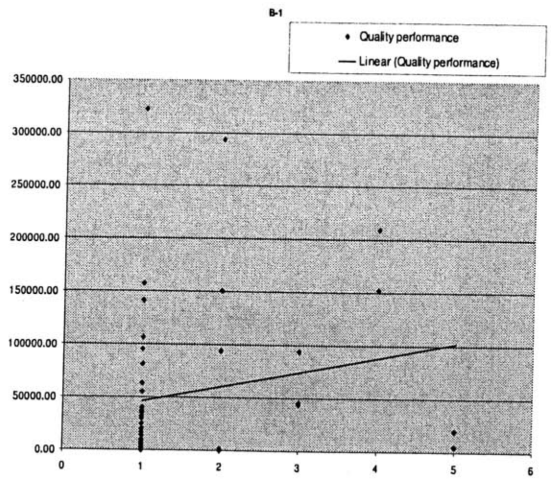
B-1
Quality performance
Linear (Quality performance)
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200000.00
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100000.00
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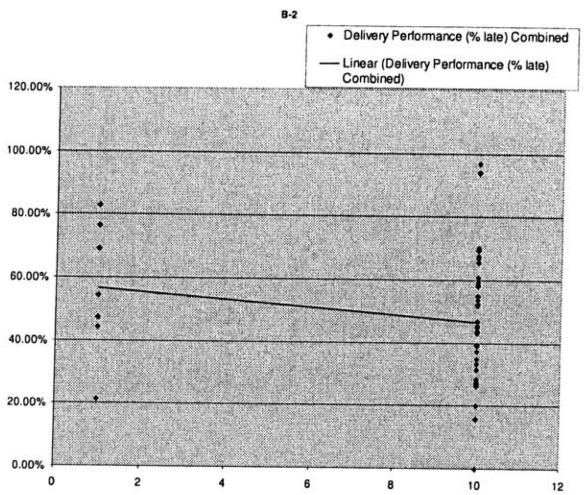
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Linear (Delivery Performance (% late) Combined)
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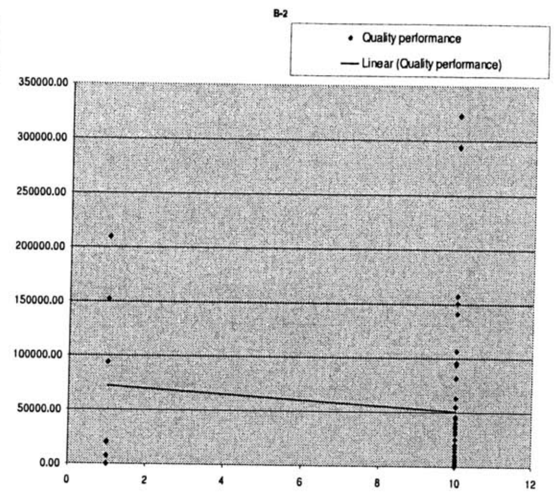
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Quality performance
Linear (Quality performance)
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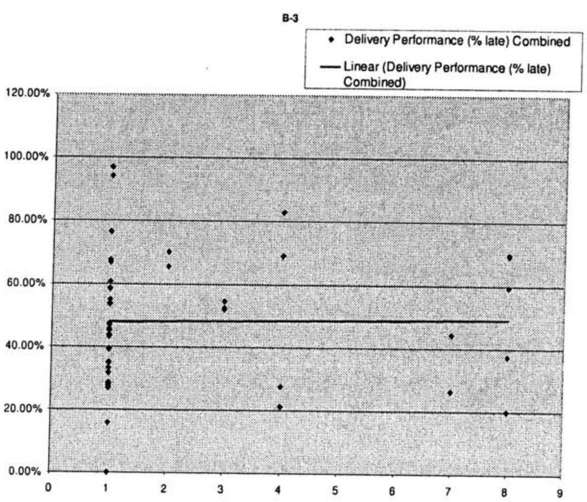
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Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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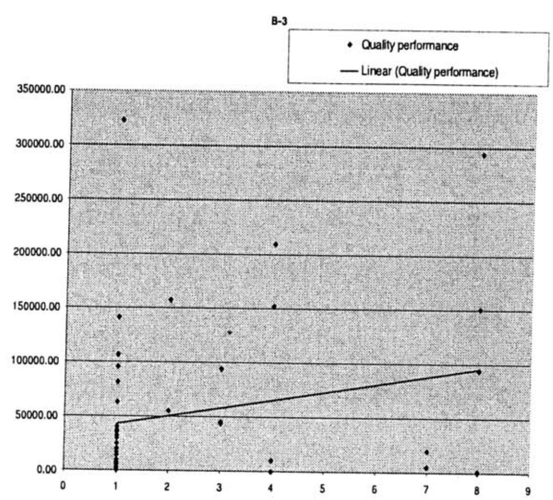
B-3
Quality performance
Linear (Quality performance)
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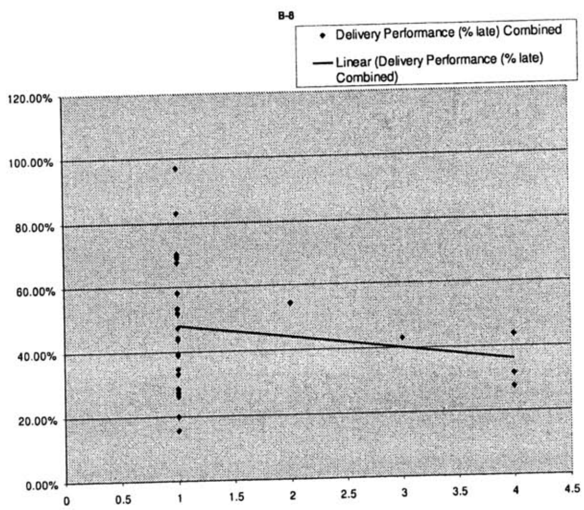
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Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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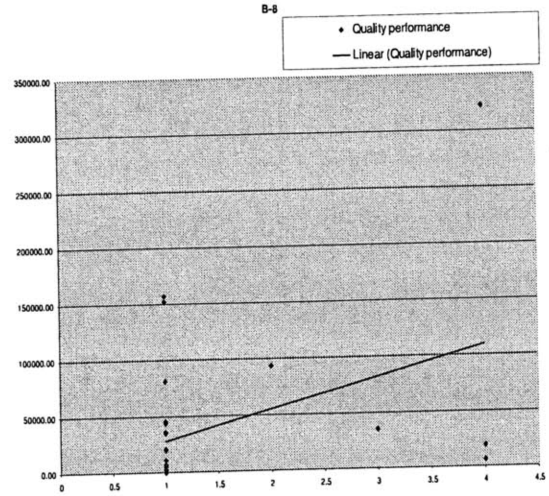
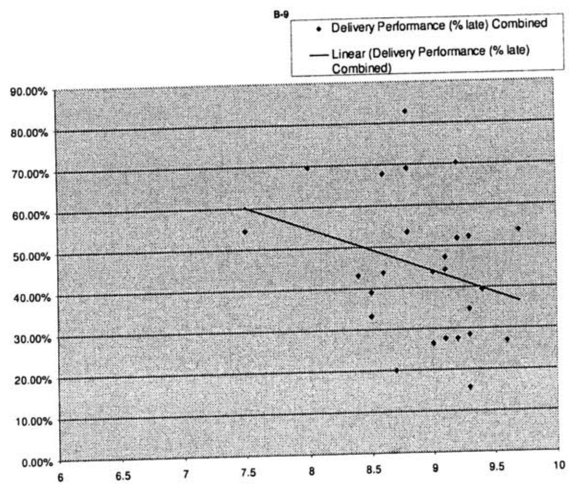

B-8
Quality performance
Linear (Quality performance)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Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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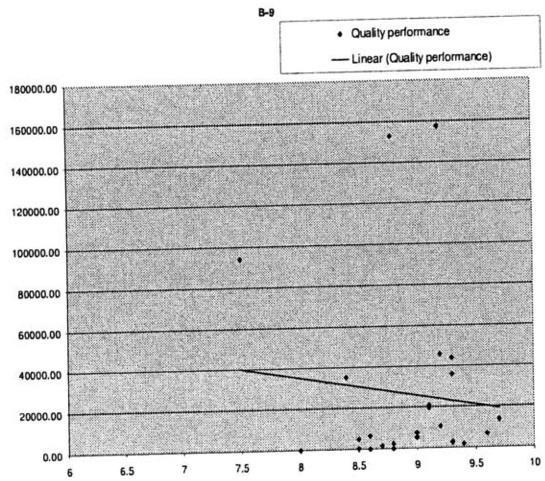
B-9
Quality performance
Linear (Quality performance)
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140000.00
120000.00
100000.00
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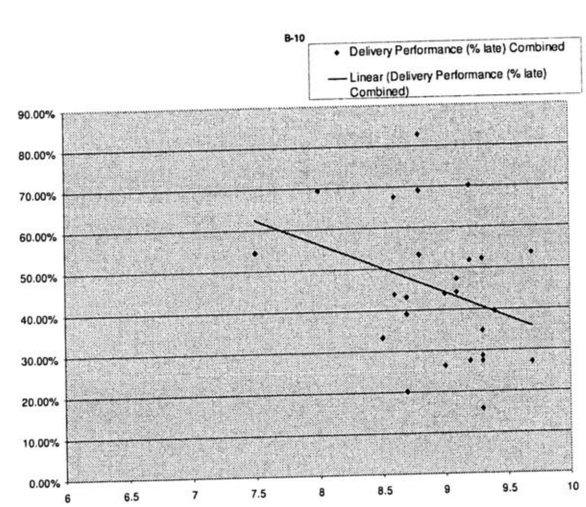
B-10
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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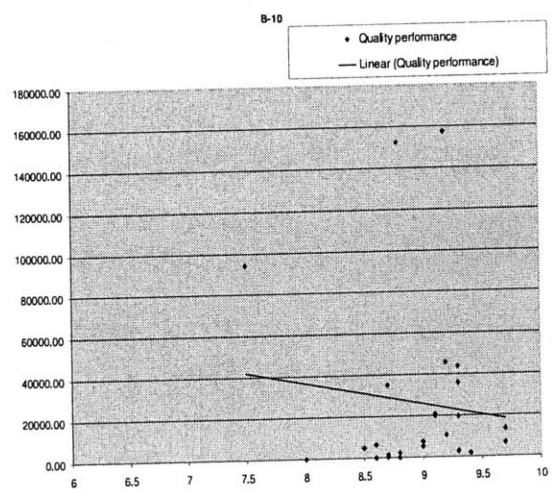
B-10
Quality performance
Linear (Quality performance)
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120000.00
100000.00
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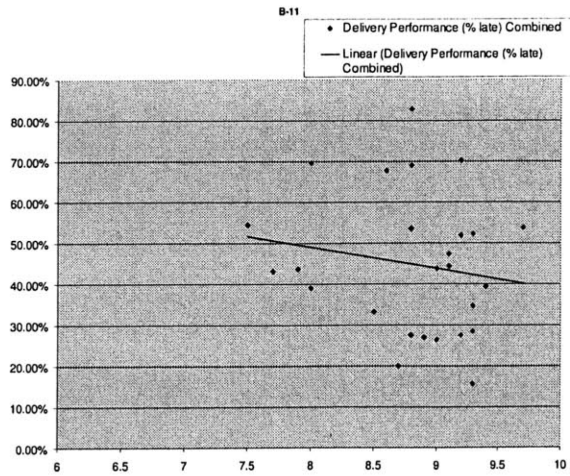
B-11
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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50.00%
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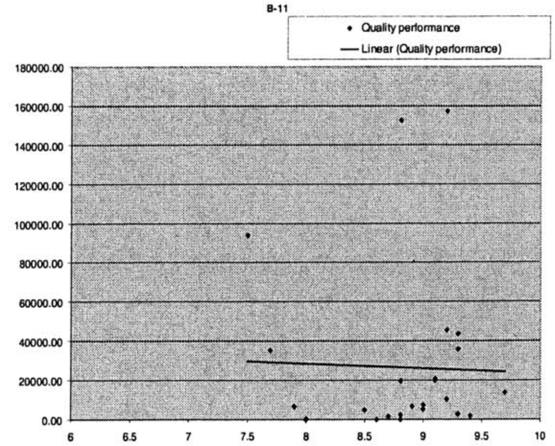
B-11
Quality performance
Linear (Quality performance)
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140000.00
120000.00
100000.00
80000.00
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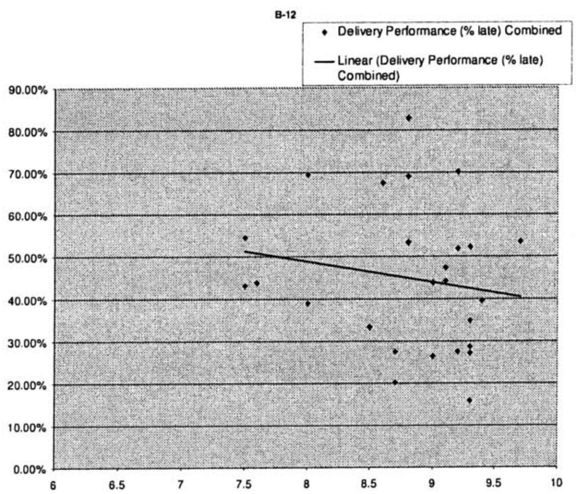
B-12
Delivery Performance (% late) Combined
Linear (Delivery Performance (% late) Combined)
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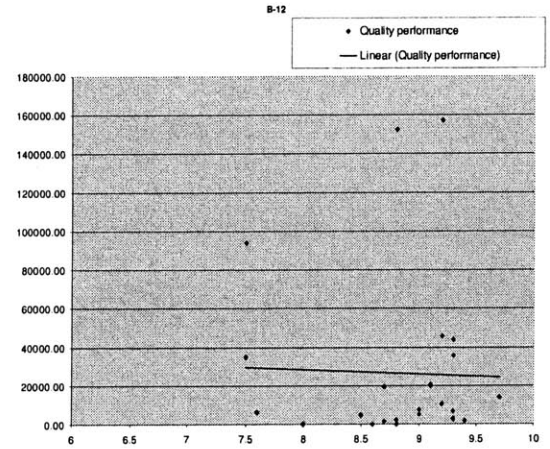
B-12
Quality performance
Linear (Quality performance)
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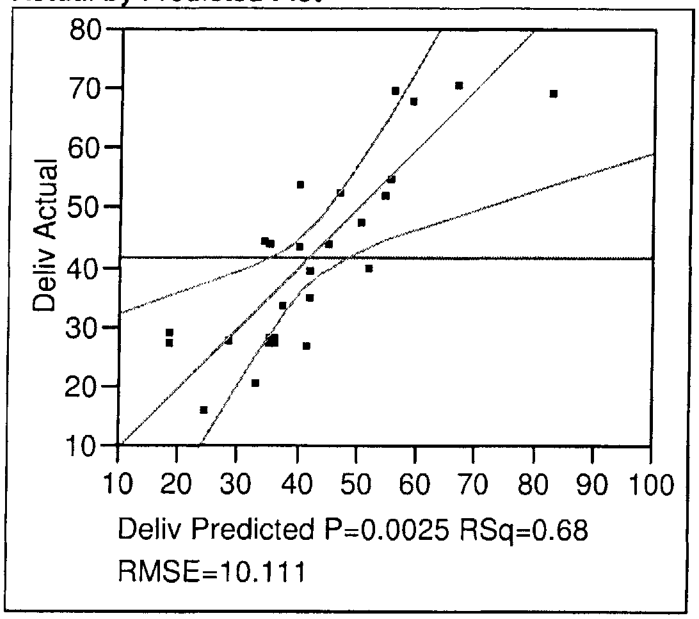
Appendix 2 – Model Regression Printouts

Response Deliv
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.68114
RSquare Adj	0.561567
Root Mean Square Error	10.11065
Mean of Response	41.82565
Observations (or Sum Wgts)	23

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	3493.9321	582.322	5.6965
Error	16	1635.6045	102.225	Prob > F
C. Total	22	5129.5366		0.0025

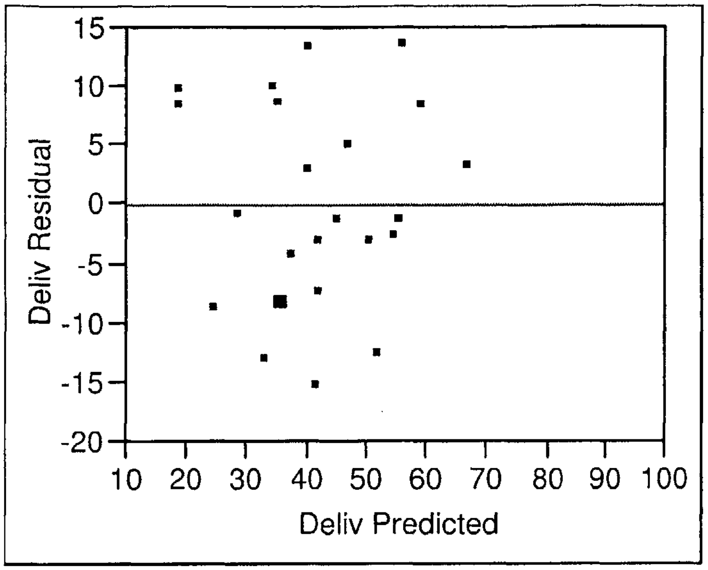
Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	203.88011	41.47801	4.92	0.0002
F-5	-4.655456	1.401253	-3.32	0.0043
F-6c{5.5-3.25&1}	-7.971682	2.871652	-2.78	0.0135
F-6c{3.25-1}	-12.54417	4.562795	-2.75	0.0143
F-8{7.75&5.5-10}	-6.717297	2.989993	-2.25	0.0391
O-8	-58.2893	13.84867	-4.21	0.0007
B-9	42.225925	13.62475	3.10	0.0069

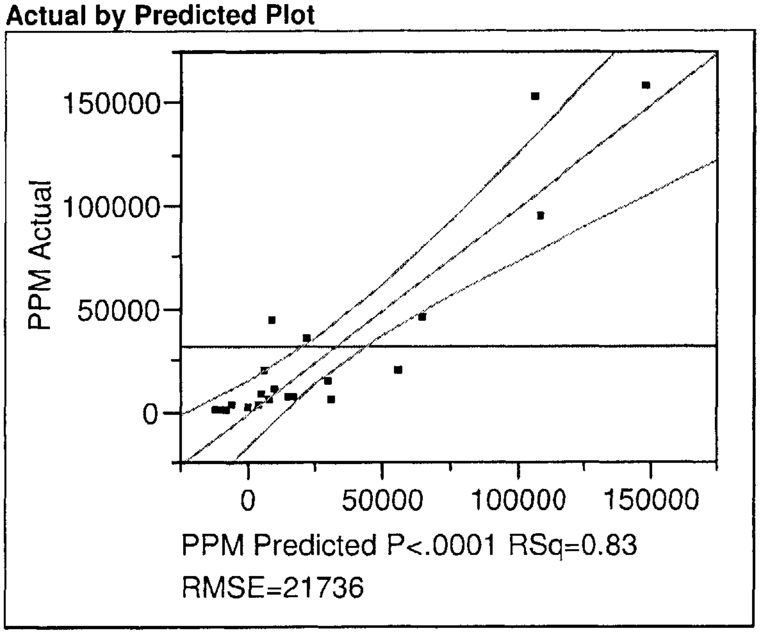
Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
F-5	1	1	1128.3647	11.0380	0.0043
F-6c{5.5-3.25&1}	1	1	787.7610	7.7061	0.0135
F-6c{3.25-1}	1	1	772.6459	7.5583	0.0143
F-8{7.75&5.5-10}	1	1	515.9492	5.0472	0.0391
O-8	1	1	1811.0073	17.7158	0.0007
B-9	1	1	981.8830	9.6051	0.0069

Residual by Predicted Plot



Response PPM
Whole Model
Actual by Predicted Plot



Summary of Fit

RSquare	0.833834
RSquare Adj	0.800601
Root Mean Square Error	21735.84
Mean of Response	33047.21
Observations (or Sum Wgts)	19

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	3.55616e10	1.1854e10	25.0904
Error	15	7086702748	472446850	Prob > F
C. Total	18	4.26483e10		<.0001

Parameter Estimates

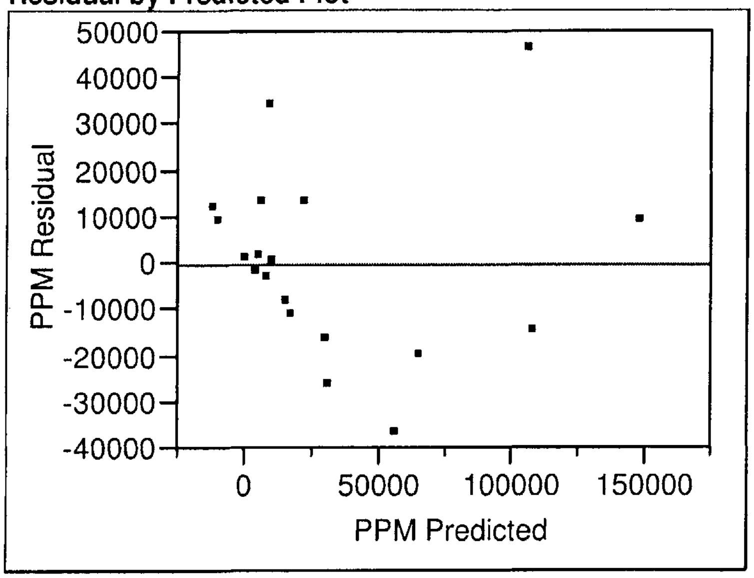
Term	Estimate	Std Error	t Ratio	Prob>|t|

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-167190	60402.39	-2.77	0.0144
F-1a[1]	12953.011	6028.903	2.15	0.0484
O-4	18756.286	2605.203	7.20	<.0001
O-13	19033.757	6688.637	2.85	0.0123

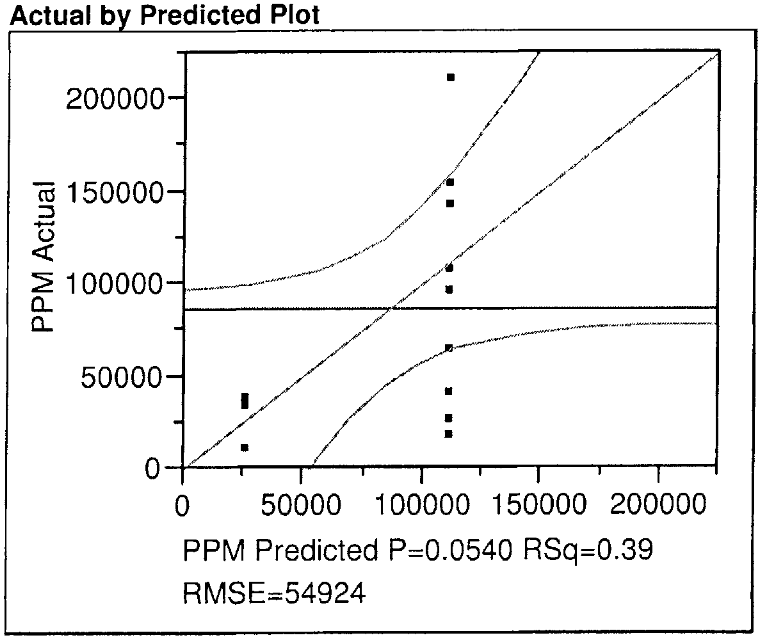
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
F-1a	1	1	2180809580	4.6160	0.0484
O-4	1	1	2.44886e10	51.8335	<.0001
O-13	1	1	3825839101	8.0979	0.0123

Residual by Predicted Plot



Response PPM
CPA SubModel
Actual by Predicted Plot



Summary of Fit

RSquare	0.389052

RSquare Adj	0.312684
Root Mean Square Error	54923.64
Mean of Response	86553.8
Observations (or Sum Wgts)	10

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1.53678e10	1.5368e10	5.0944
Error	8	2.41329e10	3.01661e9	Prob > F
C. Total	9	3.95007e10		0.0540

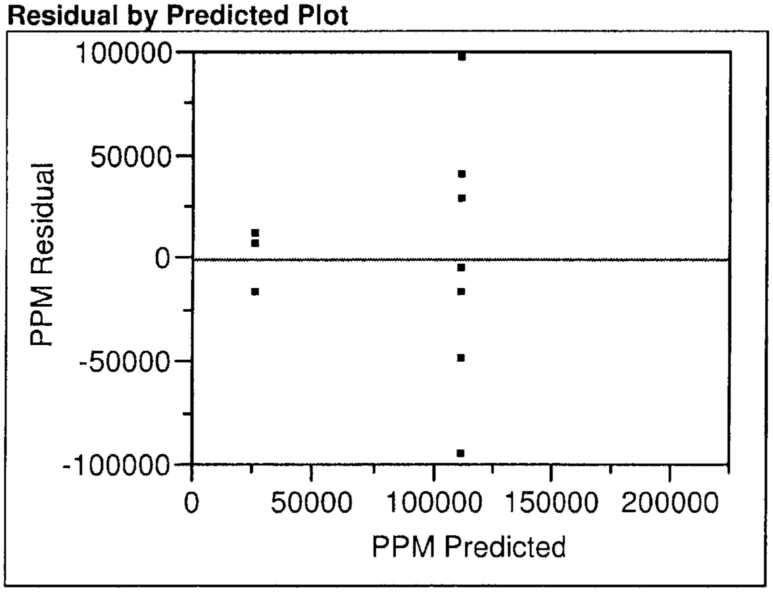
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	69444.714	18950.46	3.66	0.0064
F-7[1]	42772.714	18950.46	2.26	0.0540

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
F-7	1	1	1.53678e10	5.0944	0.0540

Residual by Predicted Plot



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