Predictive Metrics for Supply Chains

by

Linda Haydamous

B.E. Electrical Engineering
American University of Beirut
Beirut, Lebanon, 2005

M.S. Engineering Management
New Jersey Institute of Technology
New Jersey, USA, 2006

Submitted to the Engineering Systems Division in Partial Fulfillment of the

Requirements for the Degree of

Master of Engineering in Logistics

at the

Massachusetts Institute of Technology

June 2009

Signature of Author.....
Engineering Systems Division
May 8, 2009

Certified by.....
5/21/09
Dr. Larry Lapide
Director, Demand Management, MIT Center for Transportation & Logistics
Thesis Supervisor

Accepted by.....
Prof. Yossi Sheffi
Professor, Engineering Systems Division
Professor, Civil and Environmental Engineering Department
Director, Center for Transportation & Logistics
Director, Engineering Systems Division

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Dr. Larry Lapide for assisting me patiently in developing this thesis and for connecting me to industry experts who brought valuable insights to my research. His efficient and quick responses and his guiding comments were crucial to completing this thesis.

I am distinctively grateful to Mr. Gregory Moseley, Director of Major Subcontracts for the Boeing NCS programs, for proposing this thesis topic and assigning a group to help me get the information I needed. I am also very grateful to Ms. Peggy Berry, Director of Supplier Management for Boeing C3 Networks for sponsoring my research.

I am very thankful to The Boeing Company, my employer, for sponsoring my study here at MIT, and especially to Ms. Deborah Wilson, my manager, for making this possible and for supporting me through my telecommuting.

I would like to express many thanks to Ms. Rosalind Chu, Supplier Program Manager for Boeing C3 Networks and Mr. Daniel Stoff, Procurement Agent of The Boeing Company, for leading the support effort of this research and for being so instrumental and diligent in facilitating meetings with Boeing personnel, and getting me the needed information.

My gratitude goes to the Boeing program managers, who granted me interviews and documentations for their programs and facilitated my calls and surveys to their suppliers. I would also like to thank Kirstin Parks and Scott Hunter who granted me interviews to explain the current enterprise-wide performance measurement systems at Boeing.

I would like to show my great appreciation to industry experts who took time from their busy schedules to grant me interviews and provided a current perspective to my thesis: (in alphabetical order) Marissa Brown, Senior Program Manager at APQC, Gary Cokins, Global Product Marketing Manager for Performance Management at SAS, Pierre Mitchell, Director of Procurement Research and Advisory at The Hackett Group and Steven Wade, Director of Benchmarking at CAPS Research.

I am very thankful to the MLOG professors and staff, and a special thanks to Dr. Chris Caplice and Dr. Jarrod Goentzel for making MLOG such an enriching experience. In addition, I would like to thank all my MLOG friends for making my stay at Boston pleasant and fun.

My warmest gratitude goes to my boyfriend, Amine Hayek, for being there throughout my MIT experience and beyond, and for being such a supportive, inspiring, and fun person to be around.

Many thanks to my brother Gaby and my sister Carla for giving me perspective and inspiration.

Finally, there are no words to thank my parents, Antoine and Mona for their infinite love and sacrifices. Without you I wouldn't be here today!

Predictive Metrics for Supply Chains

by

Linda Haydamous

Submitted to the Engineering Systems Division on May 8, 2009
in partial fulfillment of the requirements for the degree of Master of Engineering
in Logistics at the Massachusetts Institute of Technology

ABSTRACT

The economic crisis that the world has been experiencing since 2008 has led several organizations to announce record losses and bankruptcies. But couldn't the chief factors have been predicted, at least to some extent? What if the critical success factors of a company are predicted and evaluated, wouldn't that eliminate, or at least cushion, such misfortunes?

In this thesis I provide a framework for developing predictive metrics for supply chains. The goal of these metrics is to provide a key set of indicators, aligned with the business strategy, that provide early warnings of problems or early signals of successful project completion. They allow organizations to analyze risks and provide supply chain managers with a forward-looking approach to align their strategy with performance outcomes. My target audience is the Aerospace and Defense (A&D) industry but the results could be expanded across industries.

There is no one-size-fits-all set of predictive metrics. Finding the optimal set depends on the project focus and the supplier type. In this thesis I measure performance in the four areas of cost, schedule, quality and technical. I use system dynamics models to develop my framework and employ three A&D programs as case-study subjects to illustrate the implementation of the framework.

Thesis Advisor: Dr. Larry Lapide
Title: Director, Demand Management, MIT Center for Transportation & Logistics

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

Chapter 1 INTRODUCTION

The world economic crisis of 2008 has forced organizations to inflict changes to their processes to ensure their survival. The rational response should have been to take a closer look at their performance management, assess the organization's critical success factors and ensure these are being predicted, measured and monitored. Instead, many responded to the downturn by a knee-jerk reaction: budget cuts and layoffs. Such an overreaction exhibits a flawed mentality and might have cut "beyond the fat into the nerve tissue and bone". While this tactical approach might help in the short-term, it is detrimental for the company's future (Cokins, 2009).

The key to an organization's performance improvement is focusing on enhancing its critical success factors; aligning its strategy with what it is measuring. It is not new to say "What you measure is what you get" or "You get what you inspect, not what you expect". Most, if not all, organizations today use some form of performance management systems, yet the problem lies in the fact that they continue to use metrics that have been there historically, that are not aligned with the company's strategy, that only report past information, and that lead to the wrong kind of behavior.

This was nicely stated by the late Michael Hammer in his book "The Agenda: What Every Business Must Do to Dominate the Decade":

> *"...a company's measurement systems typically deliver a blizzard of nearly meaningless data that quantifies practically everything in sight, no*

> *matter how unimportant; that is devoid of any particular rhyme or reason; that is so voluminous as to be unusable; that is delivered so late as to be virtually useless; and that then languishes in printouts and briefing books without being put to any significant purpose."* (Hammer, 2001)

An important reason behind this is that, traditionally, the physical capital was considered the primary source of wealth creation and thus organizations have typically measured performance based on financial accounting principles. Up to this day most organizations' tracking systems are still shaped to a large extent by reporting and accounting aspects. Though financial measures are certainly important, they do not reflect operational efficiency and effectiveness nor do they relate to the organizational strategy. To mitigate those shortcomings, several new supply chain measurement approaches have emerged such as the Supply-Chain Operations Reference (SCOR) model and The Balanced Scorecard. While both frameworks recognized that wealth creation is not a goal, but a result of good performance, and included non-financial factors in their measures, they were largely based on reporting past performance and did not provide a forward looking approach. It is like someone driving with the rear-view mirror instead of looking through the windshield.

In addition, there should be a clear distinction between Key Performance Indicators (KPI) and Performance Indicators (PI). PI's are the countless normal or routine measures, whereas KPI's are the measures toward strategy execution. Using a radio analogy, KPI's are the signals and PI's are the noise (Cokins, 2009). So a company should make sure not to get overwhelmed by

measuring loads of metrics that have little value, but instead should focus on those ones that drive the business.

In this thesis I provide a framework for using predictive metrics. These metrics are based on a forward looking approach, ensuring to span the horizon for possible pitfalls, and allowing managers to align their strategies with their performance outcomes. I use system dynamics models to determine the critical variables and how they affect cost, schedule, quality and technical performance of a project. After identifying the critical variables, I determine if they are predictable; if so, I identify their causal factors. The goal of predictive metrics is to identify issues early enough to prevent problems rather than correct them.

This thesis is primarily focused on the A&D industry but the results can be expanded across industries. Three programs within Boeing's Integrated Defense Systems (IDS) serve as case-study subjects of this thesis, and information was gathered through the following five main sources:

1) Meetings with the managers and team members of each program
2) Interviews of key suppliers of each program
3) Surveys of about 70% of the major suppliers (by spend) of each program
4) Interviews of experts of the current Boeing performance measurement systems
5) Interviews with cross-industry performance measurement experts

The field of predictive metrics is relatively new at the time of writing this thesis. There is currently no predictive metrics framework in place though several publications have addressed it. Nonetheless, some organizations have started research on the subject and it likely to see

companies in the near future requiring the use of predictive metrics. In fact, Gary Cokins, in his book "Performance Management: Integrating Strategy, Execution, Methodologies, Risk and Analytics" has a chapter titled "What Will Be the Next New Management Breakthrough?" where he argues that the focus of performance management has shifted from historical reporting to forecasting and *predictive analytics* and states "Advanced organizations have realized that predictive analytics may likely be their future primary source for a competitive advantage." (Cokins, 2009).

It is worth to note here that the terms predictive metrics and predictive indicators are used interchangeably. Predictive analytics, while along the same lines, is much more quantitative and IT focused. Predictive analytics is a "systematic exploration of quantitative relationships among performance management factors" to predict future performance (Davenport, 2008).

1.1 Research Question

This study aims to provide a set of metrics that can be implemented for different production programs in the Aerospace and Defense (A&D) industry to enhance their operation. The objective is to answer the following question:

> *What set of indicators closely predicts supply chain future performance in the areas of cost, schedule, quality and technical?*

The scope is limited to production programs, i.e. no initial developmental stages are considered. In addition, the study focuses on the manufacturing supply chain of the program and does not include the maintenance supply chain which is part of the future research.

1.2 Motivation

A typical project in the Aerospace and Defense (A&D) industry involves numerous suppliers. Any rework effort is usually very costly, so it is essential to seek first-time quality and maintain efficiency and effectiveness. In addition, it is hard to monitor all those suppliers separately on a long list of metrics and align them with the company strategy, so there usually is a company-wide standard metrics system that measures supplier performance. However, such systems are sometimes too standardized to the point that they lose any meaning. They measure only past performance, have a boat-load of metrics, and in some cases are measuring the wrong variables.

Moreover, though at one time the A&D industry was not very focused on cost, with a lot of money allocated to it; it is now lying, like the rest of the industries, under the fangs of the struggling economy. Since resources are limited, managing cost is now as critical as ever. So knowing which critical factors drive the company value, predicting and measuring them are essential to understanding how to allocate resources. For all the above reasons, there is a need to have a predictive metrics framework that anticipates program performance before it is too late. This framework needs to catch problems in the supply chains early enough (when cost is minimal) to make corrective action effective, or provide an early indication of successful project completion. Such a framework will provide managers with the needed forward-looking approach to align their efforts with the desired performance outcomes.

A&D companies focus primarily on four areas of performance: cost, schedule, quality and technical; so the framework described in this thesis will provide metrics that cover all of these areas.

1.3 Thesis Organization

The rest of the thesis is organized as follows:

- Chapter 2 shows a literature survey, mainly focusing on performance measurement approaches and supply chains metrics.
- Chapter 3 provides an overview of the Aerospace and Defense (A&D) Industry, the defense contracting process, a benchmarking report of metrics used across the industry, and the future prospects of the industry.
- Chapter 4 provides an overview the company under study, Boeing, and its current supplier measurement system.
- Chapter 5 provides an in depth analysis of each of the three programs under study.
- Chapter 6 proposes tactics for predicting supply chain performance then takes a system dynamics approach to determine the critical factors driving supply chain performance.
- Chapter 7 illustrates the developed framework.
- Chapter 8 demonstrates the application of the framework to the three programs.
- Chapter 9 concludes the thesis and provides directions for future research.

Chapter 2 LITERATURE REVIEW

Identifying and using metrics in a predictive way is relatively new and very few publications have addressed the subject. There still isn't a developed framework for predictive metrics. This literature review section covers supply chain performance measurement approaches and general metrics domain knowledge. In Section 2.1 and 2.2 I describe two main approaches in detail: "The SCOR model" and "The Balanced Scorecard" and in Section 2.3 I describe selected insights from a few publications.

2.1 The SCOR Model

The Supply Chain Council (2008) developed the Supply Chain Operations Reference (SCOR) model as a baseline approach for measuring supply chain performance. It uses a process-based methodology and provides guidelines for addressing, improving and communicating cross-industry supply chain practices to all stakeholders both internal and external to the organization. The SCOR model spans from the supplier's supplier to the customer's customer and has three major sections: 1) Process Modeling, 2) Performance Measurements and 3) Best Practices. In the Process Modeling section, the SCOR model identifies five distinct management processes (Plan, Source, Make, Deliver and Return) which can be applied to supply chains regardless of their size. The SCOR model identifies three levels of process detail: 1) Process Types, which defines the scope and content, 2) Process Categories, which defines the configuration and type of the supply chain, and 3) Decompose Processes, which defines the company's ability to successfully compete in its chosen markets. The SCOR model does not address the

implementation level as this is unique to each organization. In the Performance Measurements section, the SCOR model shows more than 150 key indicators for measuring supply chain operations and here again these are organized in the hierarchical structure. Finally, the Best Practices section identifies what actions need to be taken once the performance is measured and gaps identified. It lists over 430 executable practices based on Supply Chain Council's member's experiences.

The SCOR model was one of the main pieces of literature I used. It allowed me to look at the different facets of supply chains and their performance indicators, both financial and non-financial. However, The SCOR model is a rear-view mirror methodology; it can only identify gaps once the damage is done, whereas in this research I took some of those rear-view metrics and tried to assess their predictability to identify the causes that lead to such results before they happen.

2.2 The Balanced Scorecard

The Balanced Scorecard in another key piece of literature that I used. Kaplan and Norton (1992) developed this approach as framework for performance measurement in the Harvard Business Review. The Balanced Scorecard is a performance measurement tool that not only focuses on financial outcomes but also on the operational, marketing and developmental factors. The Balanced Scorecard encouraged organizations to measure, in addition to financial outcomes, those factors that influence financial results such as process performance, market share, long term learning and skills development. The Balanced Scorecard encourages managers to select and focus on only few critical measures that determine performance. It also provides a matrix to

check the consistency of performance measurement from all levels in an organization within four perspectives: financial, customer, internal business, and innovation and learning.

I used The Balanced Scorecard approach in my analysis to ensure I maintain a view of the big picture of the organization and align my metrics with the organization's strategy. However, this approach is also a rear-view mirror one, measuring past performances and not looking at proactive measures that will predict future performance.

2.3 Other Performance Measurement Approaches

Lapide (2006) identified what constitutes an excellent supply chain. He discussed that there are no silver-bullet practices that will transform a supply chain to a most competitive one; instead, there is a strategic framework of deeper guiding principles that form supply chain superiority. He introduced the concept of a "competitively principled" supply chain, the one whose strategies, operating models, performance metrics and practices are aligned in a strategic framework. He further described the framework for excellence and that an excellent supply chain has four characteristics: 1) Supports, enhances, and is an integral part of a company's competitive business strategy. 2) Leverages a supply chain operating model to sustain a competitive edge. 3) Executes well against a balanced set of competitive operational performance objectives. 4) Focuses on a limited number of tailored business practices that reinforce each other to support the operating model and best achieve the operational objectives. Finally he categorized organizations in three dimensions: Customer Response, Efficiency and Asset Utilization and stated that each organization has a different balance among these three dimensions and based on that balance it needs to strike the correct strategy to achieve excellence.

I used Lapide's framework to segment the programs and develop specialized sets of metrics based on the focus of each of them.

Sauder and Morris (2008) defended the fact the simpler the supply chain metrics, the better. He identified flaws with using the SCOR model as is since it is too complicated for anyone to make sense of the information. He suggested using a focused set of metrics since the majority are derivatives of one another. He provided three best practices to enterprise performance measurement: 1) Automate Data 2) Establish Core Datasets and 3) Free Data from its silos. He argued that the key to success with supply chain metrics is to keep the number small, ensure they are actionable, provide relevant consistent metrics to all levels and deliver the metrics broadly.

Lehmann and O'Shaughnessy (1982) argued that in order to develop a set of metrics one must start by classifying different criteria into an exhaustive and mutually exclusive list of categories. They proposed five categories as follows: economic, adaptive, performance, integrative, and legalistic. Later, Wilson (1994) argued that the first four categories can approximately be equated to price, delivery, quality, and service. I further built on Wilson's approach and modified her categories slightly to fit my aerospace and defense focus; thus my categories became: cost, schedule, quality and technical.

Chan and Qi (2003) identified a systematic approach that differentiates six core processes in supply chains: supplier, inbound logistics, manufacturing, outbound logistics, marketing and sales, and end customers. They measured the performance of each process in three dimensions: input, output and composite measures. They proposed a holistic supply chain performance measurement method which introduces fuzzy measures (such as human judgment) to address

practical situations. This paper helped me look at several processes that affect supply chain performance to come up with a potential list of variables that affect performance.

Gunasekaran et. al (2004) divided the measures based on functional hierarchy in strategic, tactical and operational levels. Hierarchy is based on the length of activities and the likelihood to influence different levels of management. They also describe metrics used in the supply chain processes of planning, sourcing, making or assembling, delivery and customer at each level. A survey was sent out to companies to evaluate what set of metrics is most useful. Finally a set of metrics was recommended.

Huang and Keskar (2007) collected, categorized and partitioned current Original Equipment Manufacturing (OEM) metrics in seven categories: reliability, responsiveness, flexibility, cost and financial, asset and infrastructure, safety and environmental. Furthermore they organized these categories into three tracks, namely: supplier related, product related and society related, for easier user configuration. The authors suggest choosing metrics that are aligned with the business strategy. They point out that using the product type, supplier type and integration level of OEM and suppliers provides guidance to choose the correct set of metrics.

Kleijnen and Smits (2003) analyzed supply chain metrics using the balanced scorecard approach and they recommended designing a simulation model based on the scorecard to determine how performance metrics react to environmental and managerial factors and to what level those metrics are correlated.

As seen in this chapter, there are many frameworks already developed for measuring supply chain performance. In addition, several publications have addressed and improved various

deficiencies in them. However, the vast majority of the metrics traditionally used are reactive or rear-view focused, and there is currently no framework for predictive metrics that has a forward looking approach to supply chain performance management.

My research provides a framework for developing predictive metrics that anticipate supply chain performance early enough to make corrective action effective. I used a system dynamics approach to identify the critical factors affecting supply chain performance. I provide different sets of predictive metrics depending on the focus of the program under study as well as the type of supplier.

Chapter 3 THE AEROSPACE & DEFENSE INDUSTRY

The global aerospace and defense industry is a multibillion dollar industry and has integrated supply chains spanning most of North America, Europe and Asia. Its main product segments are: aircrafts, space systems, and weaponry. It is typical to see the same suppliers providing products to more than one of these segments, primarily because of the many shared focuses between the commercial and military divisions. This industry operates in a highly regulated environment and requires a very large capital investment, both of which make it an industry with very high barriers to entry (Cizmeci, 2005).

Since my research is centered on the defense sector, and the case-study subjects were selected from there, the rest of this chapter will be chiefly focused on profiling the defense industry, its supply chain and its position in the current economy.

3.1 Defense Budget Planning

The defense industry is highly regulated; everything from weaponry demand to cost allocation is mandated by the US government. Except in times of war, demand for weaponry is primarily driven by the US military's predicted long-term needs. Other factors such as the geopolitical climate and the US government budget allocations also play a role.

The US Department of Defense (DOD) attempts to anticipate defense needs several decades in advance. The Quadrennial Defense Review (QDR) is a process where the Pentagon conducts an

exhaustive study every four years to determine military goals and make recommendations to the Congress regarding military strategy, troop size and deployment, and weapons procurement. The last QDR was released in February 2006 and the next one is due in 2010 (Standard & Poor's, 2009).

3.2 Defense Contracting Process

The US government drives demand in the defense industry by deciding what systems are needed and selecting the supplier. The process starts by the DOD identifying a need for a certain technological system. Defense contractors (such as Boeing, Lockheed Martin, Northrop Grumman. etc) respond by bidding and submitting proposals which include their approach, capabilities they offer, schedule of execution and cost. After extensive reviews and meetings between the defense contractors and government officials, the DOD announces an award date on which it selects the prime contractor. The selection process is primarily based on price and performance, though some politics might be involved. The prime contractor becomes the customer-facing entity but typically selects many subcontractors to supply different components or services toward the end product.

This defined, funded effort that seeks to provide a new or improved capability to the DOD is called a program. Examples of programs are the F-22 fighter aircraft and the Joint Tactical Radio System (JTRS) software-defined radio.

3.3 Types of Defense Contracts

There is a wide selection of defense contract types ranging from firm-fixed price, in which the defense contractor holds full responsibility for the performance costs and absorbs any resulting profit or loss, to cost-plus-fixed-fee, in which the defense contractor has minimal responsibility for the performance costs and receives a predetermined fixed fee (profit). However, defense contracts can be grouped into two main categories: cost-plus and fixed-price (Defense Logistics Agency, 2002). Cost-plus contracts are usually used for large developmental programs since it is difficult to estimate the actual total cost of a new program especially if it involves a major research and development effort (Standard and Poor's, 2009).

Fixed-price contracts: These can be divided into two categories: firm and incentive contracts.

- *Firm fixed-price contracts* allow the defense contractor to benefit from cost savings if he/she completes the contract under budget. However, the contractor accepts full responsibility for losses if cost overruns are incurred.
- *Fixed-price incentive contracts* allow the defense contractor to share savings based on target costs or share losses that exceed them, up to a certain predefined ceiling price. The defense contractor is responsible for any cost over that ceiling.

Cost-plus contracts: These can be divided into three categories:

- *Cost-plus fixed fee contracts* include a reimbursement of allowable costs plus a fixed fee regardless of the program's final costs.

- *Cost-plus incentive fee contracts* include a reimbursement of allowable costs plus increases or decreases in the fixed fee within a certain range, based on whether the defense contractor completes the program under or over budget.
- *Cost-plus award fee contracts* include a reimbursement of allowable costs and provide the defense contractor with an award fee based on its performance against predetermined targets.

With both categories of contracts mentioned above, large contractors receive 75%, small contractors receive 90% and small "disadvantaged" contractors receive 95% of the incurred costs in monthly payments. The complete balance (including profits or incentive fees) is due upon final delivery of the product (Defense Logistics Agency, 2002 and Standard & Poor's, 2009).

3.4 Supply Chain Management Benchmarking in Aerospace and Defense

CAPS Research, which is a global research organization jointly sponsored by the W.P. Carey School of Business at Arizona State University and the Institute of Supplier Management (ISM), published on April 12, 2009 a supply chain benchmarking report for the aerospace and defense industry. In this report, CAPS Research surveyed 26 aerospace and defense companies and provided benchmarks for different supplier management performance indicators (CAPS Research, 2009). In this section I provide some of these benchmarks that I deem important for my predictive metrics research.

According to the survey (see Figure 3.4.1), almost half (44%) of the supply management spending is on subcontracts, followed by general procurement at 31%. This is primarily because of the specialized nature of most components in aerospace and defense. In addition, as seen in

Table 3.4.1, only 56.33% of total annual spend is sourced through a formal competitive process. This means that there is still a large percentage that is being either sole-sourced or purchased from a convenient supplier.

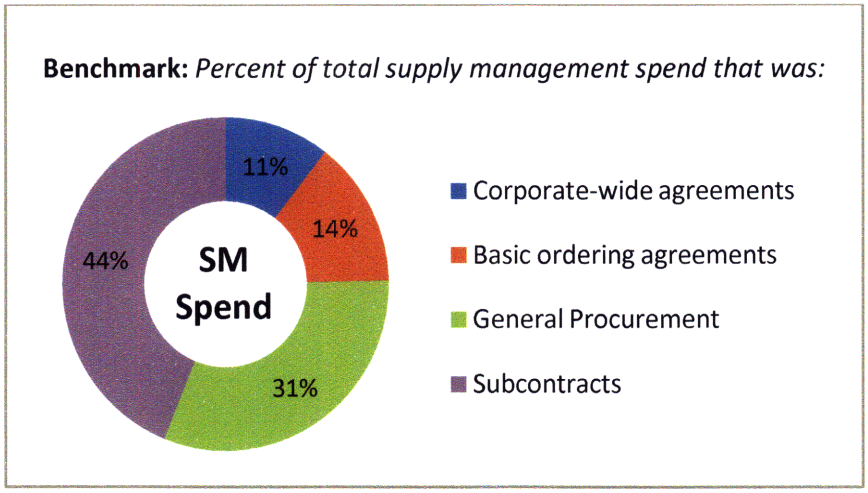


Figure 3.4.1: Supply Management Spend
Adapted from CAPS Research, 2009.

Sole-sourcing generally leads to higher prices than if the same product or service was open to competitive bidding. However, competitive bidding is arduous and time-consuming so companies often opt for a more convenient solution. Particularly in the aerospace and defense industry, where products continue to become more specialized, once a company selects a supplier, more often than not, it will continue working with him/her as a sole-source since there is a large overhead cost involved in switching suppliers. This often leads to suboptimal cost and performance outcomes.

Table 3.4.1: Annual Spend through Competitive Processes
Adapted from CAPS Research, 2009

Benchmark: *Percent of total annual spend that is sourced through a formal competitive process*	
Mean	**56.33%**
Minimum	14.00%
Maximum	99.00%
Median	60.00%

As suggested in Table 3.4.2 where 7.74% of suppliers account for over 80% of total spend, an aerospace and defense contractor typically has very few major suppliers supplying the bulk of the product. This is due to the nature of the products involved in this business: specialized and expensive.

Table 3.4.2: Percentage of Suppliers Responsible for Total Spending
Adapted from CAPS Research, 2009

Benchmark	Mean	Minimum	Maximum	Median
Percent of active suppliers that account for 80% of total spend	**7.74%**	0.26%	35.71%	6.08%
Percent of active suppliers that account for the top 20% of total spend	**0.38%**	0.01%	2.08%	19.00%

Table 3.4.3 addresses the supplier measures that aerospace and defense companies currently use as well as their importance rating. It is evident that the mostly used measures, by far, are supplier quality (100%) and supplier on-time delivery (96%). These results are expected: since this is a highly regulated industry with its product potentially affecting many people's lives, quality is of utmost importance. Furthermore, products are highly integrated and a delay in one component has the potential to delay the whole assembly line.

It is interesting to see that one of the two most rarely implemented measures is supplier cost reduction (50%). I believe the low percentage for supplier cost reduction is due to the fact that the previous few years were very lucrative for this industry and the focus largely shifted to

performance; however, as I describe in the following section (Section 3.5) the current market situation is likely to mandate increasing the concentration on cost in the near future. This idea is further reinforced by the importance ratings in Table 3.4.3 where supplier total cost of ownership, supplier affordability, and supplier cost reduction received ratings of 4.17, 4.00 and 3.92 out of 5 respectively. These are the three most highly rated measures after supplier quality (4.8) and supplier on-time delivery (4.5).

Table 3.4.3: Survey of Supplier Measures Implementation and Importance
Adapted from CAPS Research, 2009

Benchmark: *Percent of organizations that include the following measures in their supplier performance rating system/process. Of those organizations that include the supplier performance measure, level of importance (1=least important, 5=most important) placed on that measure.*		
	"Yes"	**Rating**
Maturity of supplier's quality management systems/processes	60.00%	3.60
Performance to expectations for sub-tier management	41.67%	3.50
Risk Issues/mitigation	64.00%	3.56
Supplier affordability	64.00%	4.00
Supplier capacity	54.17%	3.69
Supplier cost reduction	50.00%	3.92
Supplier innovation expertise	52.00%	2.92
Supplier management expertise	54.17%	3.15
Supplier on-time delivery	96.00%	4.50
Supplier quality	100.00%	4.80
Supplier resposiveness/flexibility	75.00%	3.72
Supplier total cost of ownership	52.17%	4.17
Third party approved quality assurance programs	52.00%	3.83

The least implemented measure is performance expectation for sub-tier management at 41%. I believe this is because companies still predominantly use historical reporting methods that record measurable past performance and that do not provide a look forward toward the future. As I describe in Chapter 5, there are key indicators to anticipate program performance and in some cases, one of these indicators is sub-tier supplier performance. The importance rating on this

measure is also one of the lowest (3.5), which means that there might not yet be an understanding of the significance of such non-direct measures.

Table 3.4.4: Survey of Supply Management Initiatives Implementation and Importance
Adapted from CAPS Research, 2009

Benchmark: *Percent of organizations that have implemented the following supply management initiatives within the supply management organization. Of the organizations that have implemented the initiatives, percent with low, medium and high levels of importannce and implementation of each initiative*					
	"Yes"		High	Medium	Low
Balanced scorecard	84.62%	Importance	50.00%	45.45%	4.55%
		Implementation	54.55%	18.18%	27.27%
Critical supplier identification	88.00%	Importance	72.73%	18.18%	9.09%
		Implementation	31.82%	59.09%	9.09%
Lean	92.31%	Importance	70.83%	16.67%	12.50%
		Implementation	33.33%	54.17%	12.50%
Managing sub-tier suppliers	76.00%	Importance	47.37%	47.37%	5.26%
		Implementation	33.33%	33.33%	33.33%
Outsourcing	84.00%	Importance	47.62%	38.10%	14.29%
		Implementation	50.00%	40.00%	10.00%
Periodic supplier business review	92.31%	Importance	54.17%	41.67%	4.17%
		Implementation	37.50%	37.50%	25.00%
Six Sigma	85.62%	Importance	50.00%	13.64%	36.36%
		Implementation	27.27%	31.82%	40.91%
Strategic alliances	100.00%	Importance	52.00%	36.00%	12.00%
		Implementation	32.00%	44.00%	24.00%
Supplier assessment/qualification	96.15%	Importance	60.00%	40.00%	0.00%
		Implementation	56.00%	32.00%	12.00%
Supplier capacity	76.00%	Importance	26.32%	73.68%	0.00%
		Implementation	10.53%	78.95%	10.53%
Supplier certification	79.17%	Importance	31.58%	68.42%	0.00%
		Implementation	31.58%	63.16%	5.26%
Supplier development	84.00%	Importance	19.05%	61.90%	19.05%
		Implementation	14.29%	47.62%	38.10%
Supplier financial health	96.15%	Importance	64.00%	36.00%	0.00%
		Implementation	20.00%	56.00%	24.00%
Supplier mentoring	76.00%	Importance	10.53%	52.63%	36.84%
		Implementation	10.53%	36.84%	52.63%
Supplier retention	64.00%	Importance	56.25%	31.25%	12.50%
		Implementation	25.00%	43.75%	31.25%

Table 3.4.4 lists a survey of supply management initiatives' implementation and importance. Overall the numbers are not very far off and aerospace and defense companies seem to be on the look for initiatives that will help enhance their operation.

3.5 A Look towards the Future of the US Defense Industry

Standard & Poor's industry survey of the aerospace and defense industry published on February 12, 2009 argues that the US defense industry will be facing slowing growth in the near future toward the rate of inflation or even lower.

Standard and Poor's expects the defense industry – after having made record profits in 2006 and 2007, largely backed by the massive spending on the Global War on Terror (GWOT) – to slow down significantly based on three primary factors:

- Drawdown of US troops
- Budget deficits due to decreasing tax revenues and sharp increases in spending
- Continued growth in the entitlements budget such as Social Security, Medicare, etc.

To cope with the slowing economy, the DOD will have to cut costs where possible. DOD officials state that "defense programs that do not have a lot of "sunk" costs (pre-existing investment), that are experiencing cost growth, and whose missions do not line up well with current priorities, face the possibility of cuts." In addition, defense contractors have been protesting large contract losses such as the combat search and rescue helicopter (CSAR-X) and the aerial refueling taker (KC-X) programs, which forced the Pentagon to delay their awards. Such delays inflict significant losses on defense contractors (Standard & Poor's, 2009).

Chapter 4 BOEING – A COMPANY OVERVIEW

The Boeing Company is a major Aerospace and Defense (A&D) corporation with $60.91 Billion in revenue (Fiscal Year 2008). It is headquartered in Chicago, IL, USA and operates in over 70 countries. In addition to building commercial and military aircrafts, Boeing designs and manufactures rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles and advanced information and communication systems. It is a major provider to NASA, operating the Space Shuttle and International Space Station. Boeing employs over 160,000 people worldwide, has customers in more than 90 countries and is one of the largest U.S. exporters in terms of sales (The Boeing Company, 2009-a).

4.1 Business Units

Boeing is comprised of four main business units: Boeing Commercial Airplanes (BCA), Integrated Defense Systems (IDS), Boeing Capital Corporation (BCC) and Shared Services Group (SSG). BCA and IDS are the two chief revenue generating units and they are supported by BCC and SSG. Each unit's role is described as follows:

- Boeing Commercial Airplanes (BCA): Manufactures commercial jetliners.
- Integrated Defense Systems (IDS): Provides end-to-end services for large-scale systems combining communication networks with air, land, sea and space-based platforms for global military, government and commercial customers.

- Boeing Capital Corporation (BCC): Provides financial solutions and structures financing to facilitate the sale and delivery of Boeing commercial and military aircraft, satellites and launch vehicles.
- Shared Services Group (SSG): Provides innovative and effective common services to the company's business units and Boeing Corporate to support the design and manufacture of aerospace and defense products (The Boeing Company, 2009-b)

4.2 Supplier Performance Measurements

The Boeing Company uses an enterprise-wide system called BEST (Boeing Enterprise Supplier Tool) as a centralized place to keep all up-to-date supplier information. BEST is accessible throughout the Boeing divisions and suppliers are generally granted access. Using BEST, managers are able to see custom reports and to "drill down" into data to understand reporting at different levels (The Boeing Company, 2009-c).

Within BEST, there's a tool called SPM (Supplier Performance Measurement) that collects, processes, and reports supplier performance information from each Boeing site and provides performance ratings at the composite, group and site levels. Performance ratings are designated as Gold (exceptional), Silver, Bronze, Yellow and Red (unsatisfactory).

SPM ratings are one the main components used when making a supplier selection decision. Suppliers can access their ratings and protest where they deem reporting was erroneous. Not only does that ensure credibility of the system, but it also promotes healthy communication between Boeing and its suppliers regarding their performance.

Supplier Performance as used in SPM consists of three items (see Figure 4.2.1): Quality, Delivery and General Performance Assessment (GPA). GPA evaluations measure supplier performance in terms of their support and capabilities in the areas of management, schedule, quality, technical and cost. Quality and delivery are based on a 12-month rolling average, whereas GPA is kept for 7 months or replaced when new assessments are conducted (The Boeing Company, 2009-c).

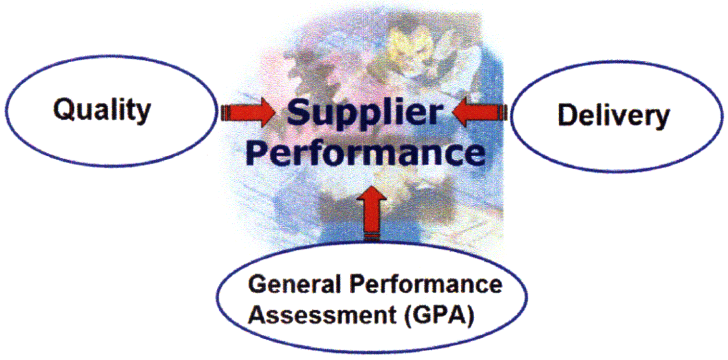


Figure 4.2.1: Supplier Performance Components in Boeing SPM
Source: The Boeing Company (2009-c)

All three categories (quality, delivery and GPA) have established thresholds for performance levels (see Figure 4.2.2). Suppliers in the Gold, Silver or Bronze rating are considered high performing.

4.2.1 Quality Measurement

Quality is measured in one of three ways depending on the type of product:

1. Traditional Methodology is used for the majority of suppliers. It measures quality in terms of product acceptance, i.e., the percentage of accepted items divided by the total items received.

2. Value Methodology is used for complex parts and assemblies. It measures quality in terms of cost of non-conformance, i.e., cost impact to Boeing of supplier defects divided by value of supplier receipts.
3. Index Methodology is used for services, systems and developmental suppliers. It measures quality in terms of several elements that are developed and agreed to by the supplier and Boeing in the form of a scorecard.

Figure 4.2.2: Boeing SPM Performance Ratings
Source: The Boeing Company (2009-c)

4.2.2 Delivery Measurement

Delivery measurement consists of two parts as shown below. Both parts are included in the report at all times.

1. Traditional Methodology measures the on-time percentage of items within the scheduled delivery window as it relates to the total number of actual items scheduled to be delivered.
2. Consumption Based Ordering (CBO) measures the total parts received outside the established ranges as related to the part number opportunities on a daily basis.

4.2.3 General Performance Assessment (GPA) Measurement

GPA is a composite rating assessing a supplier's business and program management capability. It consists of cumulative performance scores for production, developmental support services and shares service suppliers. As mentioned in Section 4.2, GPA assesses a supplier's support in the areas of management, schedule, quality, technical and cost. GPA is primarily conducted on select suppliers that represent Boeing's top spending as an enterprise. Sites or divisions can request GPA evaluation as needed.

The GPA elements are further broken down into the factors shown below:

- Management: supplier planning, implementation, and timely communications and measures.
- Schedule: effectiveness of supplier schedule disciplines.
- Quality: effectiveness of quality programs including supplier's system for quality assurance.
- Technical: engineering technical support including product development, performance and support.
- Cost: assessing suppliers' abilities to minimize cost and maximize performance.

4.2.4 Composite Rating

To determine the overall composite rating of a supplier, each of the three main performance categories (quality, delivery and GPA) should be evaluated and given a numerical value from 0 to 5 (see Figure 4.2.3). The composite rating is equal to the average of the applied numerical value, including the low performing rules for the three categories.

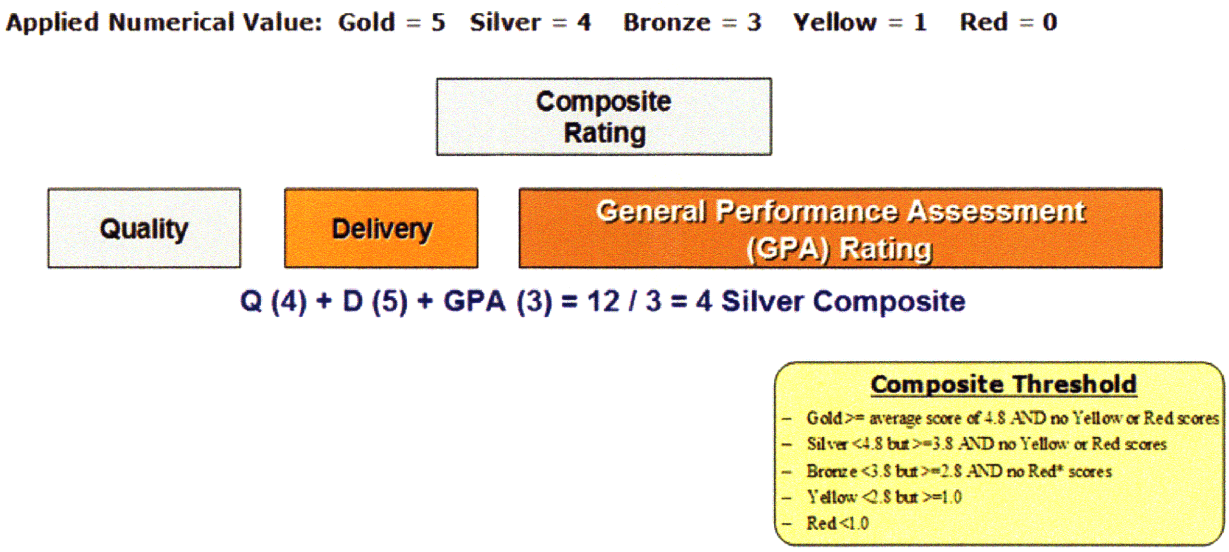


Figure 4.2.3: Boeing SPM Overall Rating Procedure
Source: The Boeing Company (2009-c)

To determine the GPA rating which already is a composite rating, the same procedure described above is followed but for the 4 GPA categories: Production, Developmental, Support Services and Shared Services as shown in Figure 4.2.4.

Finally, the computed numerical value determines the composite rating of a supplier as a Gold, Silver, Bronze, Yellow, or Red supplier.

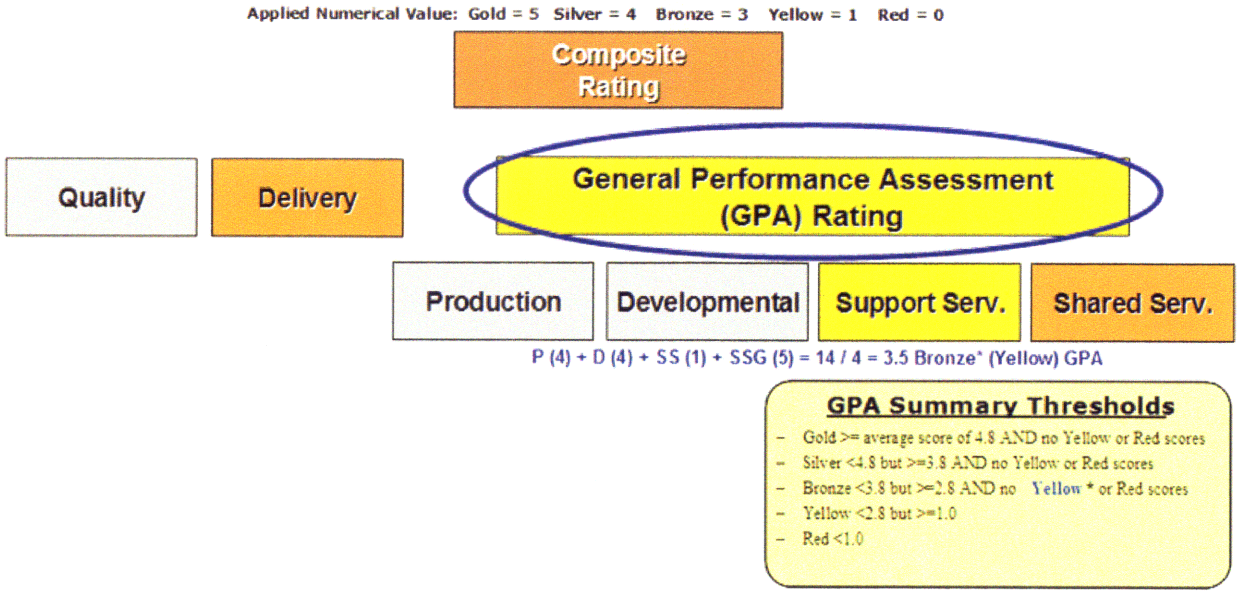


Figure 4.2.4: Boeing SPM GPA Rating Procedure
Source: The Boeing Company (2009-c)

Chapter 5 CASE STUDIES – OVERVIEW OF THREE BOEING PROGRAMS

For this thesis, I used three programs from Boeing's Integrated Defense Systems (IDS) division as case-study subjects. A program, for the purpose of this thesis, is identified as a well-defined, funded effort that seeks to provide a new or improved capability to the Department of Defense (DOD) with a finite beginning and ending dates (see Section 3.2: Defense Contracting Process).

The three programs selected are a handheld radio, a military aircraft and a missile defense system. In this chapter I analyze each of the programs, their supply chains and their performance measurement systems. Please note that all three programs surveyed were in the production state; this means they were already receiving and filling product orders. Information was mostly gathered through interviews with program managers (see Appendix A – Questionnaire for Program Managers). The names of the programs are concealed for the sake of confidentiality.

5.1 Handheld Radio

The Handheld Radio program is already providing coverage to U.S. forces worldwide: it currently produces about a thousand radios per month. Boeing is the prime contractor and its contract is based on a firm fixed-price (see Section 3.3: Types of Defense Contracts).

5.1.1 Supply Chain Profile

The Handheld Radio program has six suppliers: two providing batteries and four providing other radio components. Originally there was only one battery supplier but another one was added later

to reduce risk. Though Boeing monitors those suppliers, the products are delivered to the customer straight from suppliers without passing through the Boeing facilities. The product is delivered to the customer in two parts: the main radio assembly and the battery system.

Most of the suppliers were selected as sole-source because of the nature of the specialized radio components. They were selected, at large, based on successful history working with supplier and convenient business relations, though other considerations such as quality, delivery and cost also weighed in.

5.1.2 Supplier Performance Measurement

Like any other Boeing program, this handheld radio program performance is monitored through the company-wide BEST system (see Section 4.2). Details on exact metrics used within the system are competition-sensitive and cannot be disclosed in this report. However I administered an online survey to the suppliers of this program and interviewed a couple major suppliers to determine how they measure their internal performance and the performance of their sub-tier suppliers (see Appendix B for the survey questions).

Question: *What criteria do you use to track and evaluate your internal performance in the areas of:*
- *Cost (e.g. Cost Performance Index (CPI), Rework)*
- *Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))*
- *Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))*
- *Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):*

Cost	Schedule
Actual Cost vs quoted price Track actual costs through MRP system	On-time deliveries Schedule is tracked manually by the Program Manager

Technical	Quality
Proof of design Technical is tracked manually by the Director of Engineering	First pass yields, component defects # of rejections (internal and external) Percentage of defects

Figure 5.1.1: Handheld Radio Program Survey Question 1

Since the majority of the suppliers are small to medium size, they generally use manual measurement systems in the form of spreadsheets and reactive phone calls. In fact they aim to use simple convenient measures that are easy to measure and that add minimum overhead (see Figure 5.1.1).

Of the surveyed suppliers of the Handheld Radio program, 75% review their internal performance weekly, while the other 25% review it monthly (see Figure 5.1.2).

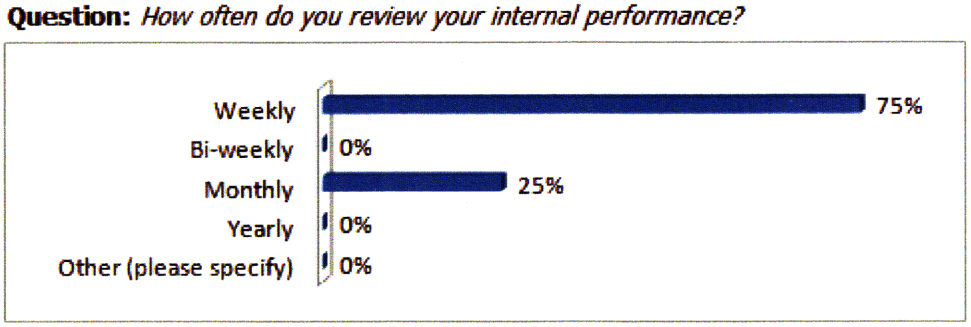


Figure 5.1.2: Handheld Radio Program Survey Question 2

Boeing often assigns sole-source suppliers for its first-tier suppliers. That is usually the case when Boeing has previously worked with that supplier and determined that what he/she does is very specialized that it made him/her a sole-source supplier. The larger and more experienced the first-tier supplier is, the less Boeing's involvement selecting its suppliers. As seen in Figure 5.1.3, 50% of the Handheld Radio program suppliers do not have their critical suppliers assigned by Boeing as sole-sources, but the other 50% have about 25% of their critical suppliers assigned. The benefit of such an assignment is that usually there is a good history working with that supplier, however some disadvantages include generally higher prices than competitive bids and larger switching costs if suppliers under-perform.

Question: *About what percentage of your critical suppliers are determined by Boeing as sole sources?*

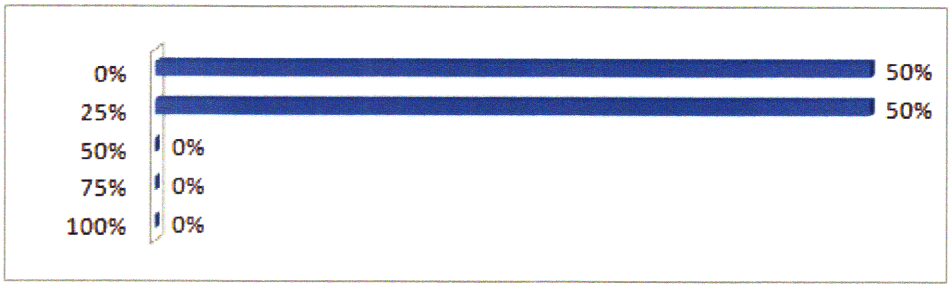


Figure 5.1.3: Handheld Radio Program Survey Question 3

In my survey I addressed the question of what factors affect the first-tier suppliers' decision in selecting their suppliers. As shown in Figure 5.1.4, 100% of suppliers use cost, delivery and quality measures whereas 75% also rely on previous working experience with the suppliers.

Question: *What criteria weighs into selecting your suppliers that are not predetermined by Boeing as sole sources? (Check all that apply)*

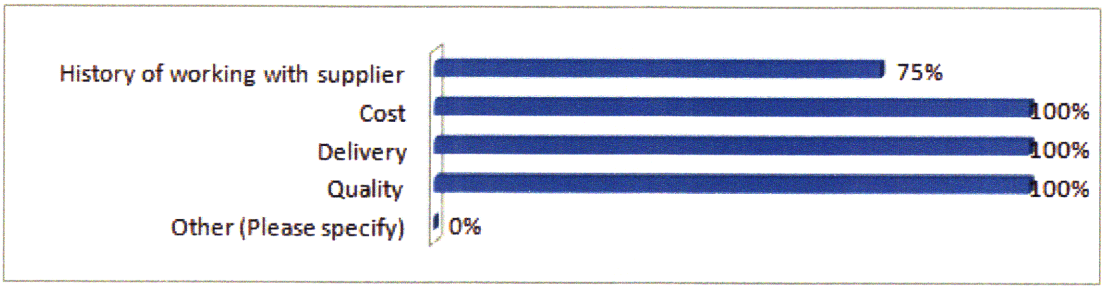


Figure 5.1.4: Handheld Radio Program Survey Question 4

Figure 5.1.5 addresses the metrics that the first-tier suppliers use to evaluate the performance of their suppliers. Overall the answers show that minimal measurements are used, and through my interviews with the suppliers it was determined that some of them use spreadsheets that are generated and updated manually to report the performance of each supplier.

Question: *What criteria do you use to track and evaluate your suppliers' performance in these areas:*
- *Cost (e.g. Cost Performance Index (CPI), Rework)*
- *Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))*
- *Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))*
- *Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):*

Cost	Schedule
competitive bids Through Visual Purchasing	Through Visual Purchasing

Technical	Quality
na By the Director of Engineering	Percentage of defects By the Manager of Quality Assurance

Figure 5.1.5: Handheld Radio Program Survey Question 5

Finally, as seen in Figure 5.1.6, none of the suppliers use any form of predictive indicators to anticipate their suppliers' performance.

Question: *Do you use any predictive indicators (such as staffing, change in management, funding ability, etc..) to anticipate your suppliers' future performance as opposed to using only backward-looking indicators?*

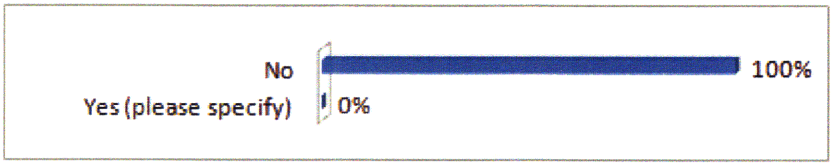


Figure 5.1.6: Handheld Radio Program Survey Question 6

5.2 Military Aircraft

The military aircraft program has contracts to provide its product to both U.S. and foreign governments: the current production rate is about fifteen aircrafts per year. Boeing is the prime contractor for this program and its contract is based on firm fixed-price (see Section 3.3: Types of Defense Contracts).

5.2.1 Supply Chain Profile

The Military Aircraft program has over 700 suppliers providing different parts of the aircraft with about 100 suppliers considered major ones based on spend. About 60%-70% of production is outsourced with the rest made in-house within Boeing facilities across the US. Boeing integrates the different components from suppliers and performs the final delivery to the customer from its facilities.

5.2.2 Supplier Performance Measurement

Like any other Boeing program, this military aircraft program performance is monitored through the company-wide BEST system (see Section 4.2). In addition, this program uses MRP (Material Requirements Planning) to maintain low level of inventory while ensuring products are available for production and delivery to customers. This program also uses measures beyond the BEST system, especially for critical suppliers, to ensure problems are taken care of as they emerge. Details on exact measures used are competition-sensitive and cannot be disclosed in this report. However I administered an online survey to the suppliers of this program and interviewed a few major suppliers to determine how they measure their internal performance and the performance of their sub-tier suppliers (see Appendix B for the complete survey questions).

This Military Aircraft program, largely due to its size, has mostly medium to large-size suppliers. As seen in Figure 5.2.1, many advanced measurements are used to track performance and the suppliers generally have somewhat integrated performance systems across their organization.

Question: *What criteria do you use to track and evaluate your internal performance in the areas of:*
- *Cost (e.g. Cost Performance Index (CPI), Rework)*
- *Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))*
- *Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))*
- *Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):*

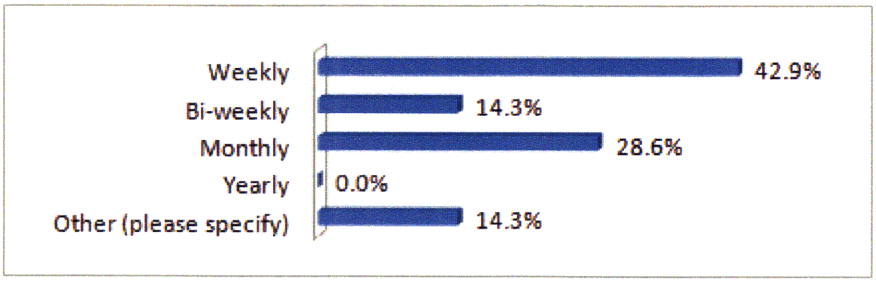
Cost	Schedule
Gross Sales Margin	Customer Supplier Performance Report (*2)
Compare cost to produce with price quoted	On-Time Delivery (*4)
Rework	Measure % of parts started on time
CPI (*2)	SPI

Technical	Quality
KPP	Percentage of Defects (*2)
Performance Metric	Customer Quality Rating (*3)
tpp	Nonconformance Report
Estimated to Actual on Efficincy & Variance by employee & dept.	cp
	Quality Tool kit

Figure 5.2.1: Military Aircraft Program Survey Question **1**

Figure 5.2.2 shows the period in which the surveyed first-tier suppliers of the Military Aircraft program review their internal performance. Most of them (42.9%) review it daily, 28.6% of them review it monthly and an equal percentage of them (14.3%) review it bi-weekly or daily.

Question: *How often do you review your internal performance?*



Specified:
Daily
Dashboard is delivered daily to executives

Figure 5.2.2: Military Aircraft Program Survey Question 2

Question: *About what percentage of your critical suppliers are determined by Boeing as sole sources?*

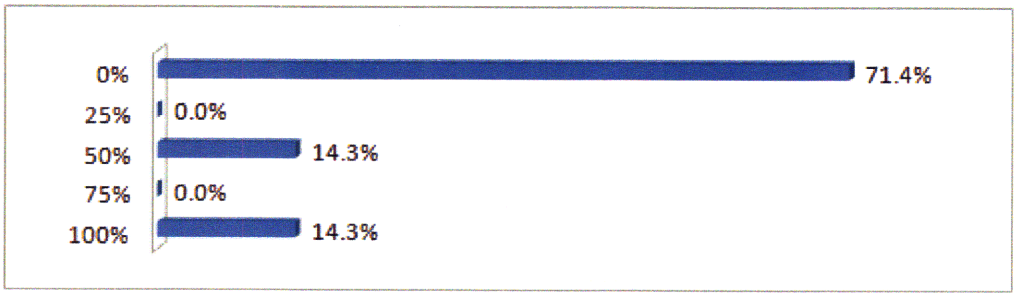


Figure 5.2.3: Military Aircraft Program Survey Question 3

Figure 5.2.3 shows that for the vast majority (71.4%) of the first-tier suppliers of this program, Boeing does not assign any sole-sources for critical suppliers. This, I believe, is due to the reasoning I provided in the previous section and that is, as the size of the first-tier supplier increases, Boeing's involvement with selecting their suppliers decreases.

Question: *What criteria weighs into selecting your suppliers that are not predetermined by Boeing as sole sources? (Check all that apply)*

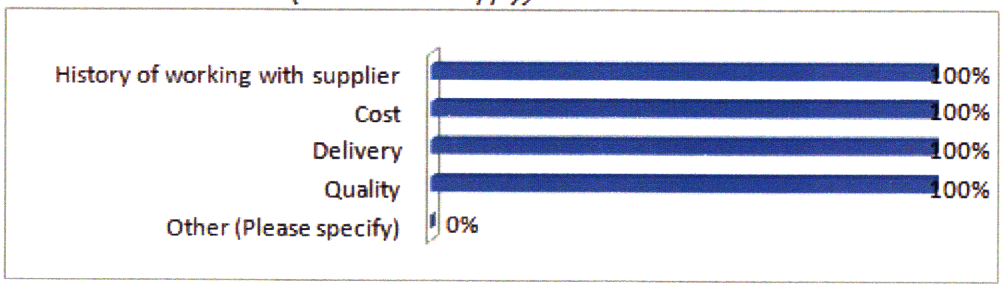


Figure 5.2.4: Military Aircraft Program Survey Question 4

Figure 5.2.4 addresses the factors that affect the first-tier suppliers' decision in selecting their suppliers and shows that 100% of suppliers surveyed use all the measures I specified in my question, namely: history of working with supplier, cost, delivery and quality.

As seen in Figure 5.2.5, the suppliers of the Military Aircraft program use more advanced measures to evaluate their suppliers' performance than the Handheld Radio does. This again, I believe is due to the size and maturity of this program as opposed to the latter.

Question: *What criteria do you use to track and evaluate your suppliers' performance in these areas:*
- Cost (e.g. Cost Performance Index (CPI), Rework)
- Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))
- Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))
- Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):

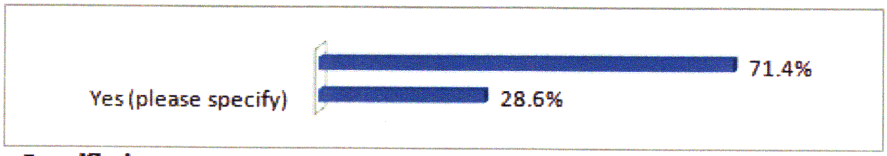
Cost	Schedule
None	On-Time Delivery (*3)
Competetive bid	Customer Performance Rating
CPI	spi
Customer Performance Rating	on time delivery
Lowest Cost	

Technical	Quality
None	Rejection Rate (*4)
TPP	Cp
Customer Performance Rating	Customer Performance Rating
	1st time quality

Figure 5.2.5: Military Aircraft Program Survey Question 5

Moreover, 28.6% of the suppliers of this program use some form of predictive indicators of performance as seen in Figure 5.2.6. From my interviews with some of these suppliers, I found that many of them have well-integrated performance management systems that span across their organization and they have been pursuing new initiatives to further improve performance.

Question: *Do you use any predictive indicators (such as staffing, change in management, funding ability, etc..) to anticipate your suppliers' future performance as opposed to using only*



Specified:
- Maintain solid commiunication with suppliers to keep up with the latest changes in their companies.
- looking at the current backlog and contracts

Figure 5.2.6: Military Aircraft Program Survey Question 6

5.3 Missile Defense

The Missile Defense program does not deliver its products to a government counterpart, but instead, to another aerospace and defense company. While Boeing is not the prime contractor for this program, it is a major supplier of the prime contractor. This program effort is currently complete and used to provide about 80 units per year. This was an extremely successful program and it had a fixed-price-incentive type contract (see Section 3.3: Types of Defense Contracts).

5.3.1 Supply Chain Profile

The Missile Defense program has one significant major supplier, once critical process subcontractor and forty other minor suppliers. Boeing maintains long term agreements with the majority of the suppliers on this program and works closely with its major supplier. It integrates different components from suppliers and performs the final delivery to the customer.

5.3.2 Supplier Performance Measurement

Like any other Boeing program, this Missile Defense program performance is reported through the company-wide BEST system (see Section 4.2). In addition, like the Military Aircraft program, this Missile Defense program uses MRP (Material Requirements Planning) to maintain low level of inventory while ensuring products are available for production and delivery to customers. Beyond those measures, the Missile Defense program uses an additional system specifically developed for this program to monitor and enhance performance daily. With the major subcontractor, for example, Boeing maintains a very close relation and they both use the same metrics and monitor and seek to enhance each others' performance. There is tight

monitoring of all suppliers on a daily basis and lessons-learned reports are produced periodically. Details on the exact measures used are competition-sensitive and cannot be disclosed in this report.

As mentioned previously, this Missile Guidance program had outstanding performance and in fact, I leveraged some approaches and metrics used within this program in my framework.

First let me note that since my surveys were mainly focused on major suppliers, and due to the nature of the supply chain of this program (see Section 5.3.1), this program had the lowest number of responses to the survey with respect to the other programs.

Question: *What criteria do you use to track and evaluate your internal performance in the areas of:*
- *Cost (e.g. Cost Performance Index (CPI), Rework)*
- *Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))*
- *Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))*
- *Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):*

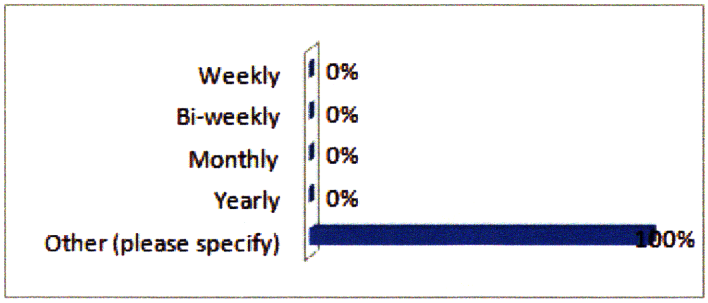
Cost	Schedule
Cost Perfomance Report - time phases expenditure - measurement of standards for touch labor to name a few.	Daily monitoring of build schedule, program reviews, Cost Perfomance Report - time phases expenditure - measurement of standards for touch labor to name a few.

Technical	Quality
IPT Reviews, Testing, Risk Management, Program Reviews, Customer, Internal Reviews.	On site montoring and buy off of equipment - Quality Management Plan - 3 part sell-off of hardware, Quality IPT and Surveillance on a daily basis.

Figure 5.3.1: Missile Defense Program Survey Question 1

Figure 5.3.1 addresses the criteria used to evaluate performance. It is clear that this program monitors many measures and performs multiple reviews and basically keeps a tight ship on its performance indicators.

Question: *How often do you review your internal performance?*



Specified:

Delivery and hardware built was reviewed daily for the entire period of performance

Figure 5.3.2: Missile Defense Program Survey Question 2

As shown in Figure 5.3.2, 100% of the major suppliers monitor their performance daily. Also as seen in Figure 5.3.3 suggests, Boeing does not enforce any sole source suppliers on its major first-tier suppliers. This is also likely due to the fact that those suppliers are large and mature corporations and have an integrated performance measurement system where they can confidently select suppliers from.

Question: *About what percentage of your critical suppliers are determined by Boeing as sole sources?*

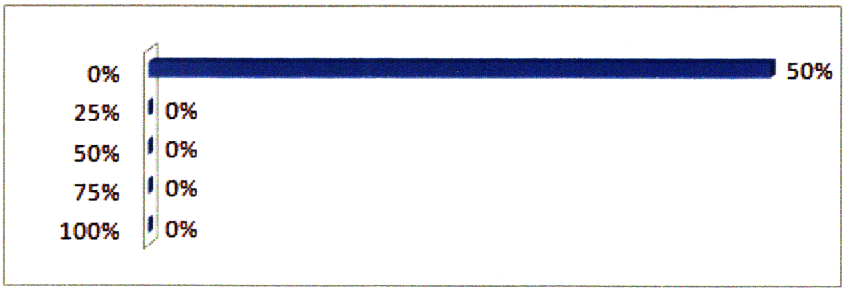
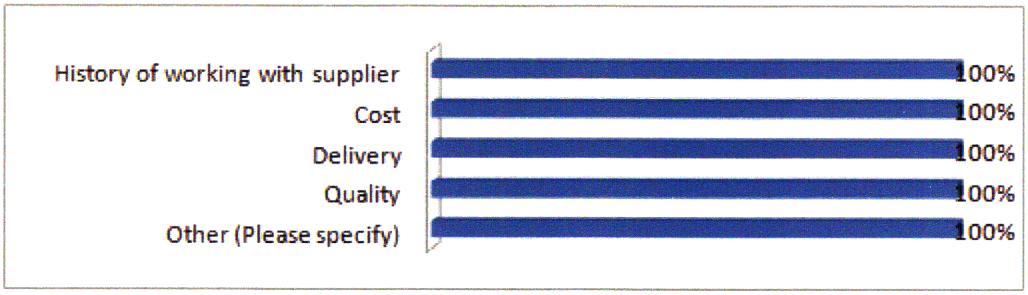


Figure 5.3.3: Missile Defense Program Survey Question 3

Figure 5.3.4 shows that the selection process of suppliers is based on many factors including history of working with supplier, cost, delivery and schedule. Furthermore, as noted in the comment, the suppliers were determined at the beginning on the program and as much as possible, a long term agreement was negotiated with them to cover the whole program lifeline.

Question: *What criteria weighs into selecting your suppliers that are not predetermined by Boeing as sole sources? (Check all that apply)*



Specified:

- All of the above. However, since this was a production run of large number of systems, the suppliers were determined at the beginning and only replaced when they went out of business due to the critical nature and qualification requirements of the parts.
- approvals for materials and processes

Figure 5.3.4: Missile Defense Program Survey Question 4

Figure 5.3.5 addresses the measures that the first-tier suppliers use to evaluate their suppliers. It is not clear from the results what exact measures are used but it shows that there are standard procedures enforced by the customer (Boeing) and in addition there are further internal procedures used to monitor this performance.

Question: *What criteria do you use to track and evaluate your suppliers' performance in these areas:*
- *Cost (e.g. Cost Performance Index (CPI), Rework)*
- *Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))*
- *Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))*
- *Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):*

Cost	Schedule
As required by customer and internal policy and procedures.	As required by customer and internal policy and procedures.

Technical	Quality
As required by customer and internal policy and procedures.	As required by customer and internal policy and procedures.

Figure 5.3.5: Missile Defense Program Survey Question 5

Figure 5.3.6 suggests that no predictive indicators were used to anticipate suppliers' performance. However, I believe the structure of the supply chain of this program, and the

continuous close relation between Boeing and its major supplier, as well risk analysis (which is part of predictive metrics) were some factors leading to this program's success.

Question: *Do you use any predictive indicators (such as staffing, change in management, funding ability, etc..) to anticipate your suppliers' future performance as opposed to using only backward-looking*

Figure 5.3.6: Missile Defense Program Survey Question 6

This page is intentionally left blank.

Chapter 6 PREDICTING SUPPLY CHAIN PERFROMANCE

As mentioned before, most performance measurement systems currently implemented at organizations are backward-looking, that is, they look at performance that had already happened, and they can, at best, be used as a means of damage-control. The primary reason for this is historical reporting; it is the way things have been done in the past. Another reason, however, is the difficulty in measuring some factors, so organizations opt to monitor those factors that *can* be measured instead of that *should* be measured. In this Chapter, Section 6.1, I provide some tactics that I deem important for probing supply chain performance then in Section 6.2 I provide system dynamics models to determine the critical factors affecting supply chain performance. Finally, in Section 6.3, I compare predictive metrics to "reactive" ones and show how they measure the same things in completely different ways.

6.1 Tactics for Predicting Supply Chain Performance

In this section I provide some tactics that are important to anticipating supply chain performance and that guide the search for predictive metrics. It is worth noting that not all of these tactics are necessarily applicable for every organization, in fact in Section 7.4 I provide a framework for selecting the right metrics based on the program and supplier types.

6.1.1 Monitoring Sub-tier Supplier Performance

In a supply chain, materials usually flow from the upstream suppliers, through the contractor to the customer (see Figure 6.1.1). So the contractor's performance is reliant on its suppliers' performance. While the contractor often assigns or approves its second or third-tier suppliers, it is usually primarily focused on monitoring its first-tier suppliers and leaves the responsibility of monitoring the further sub-tiers to them. However, a problem that arises upstream can travel throughout the chain all the way downstream. So a contractor's visibility to the performance of its sub-tiers can help him/her predict the performance of its first-tier suppliers. For example, when a second-tier supplier has a management change or goes out of business, this is likely to trickle down to the first-tier supplier. While the effect is likely to be minor in a commodity or standard part supplier, it is crucial for a specialized or critical supplier. Thus having visibility to sub-tier supplier performance can help predict the performance of first-tier suppliers.

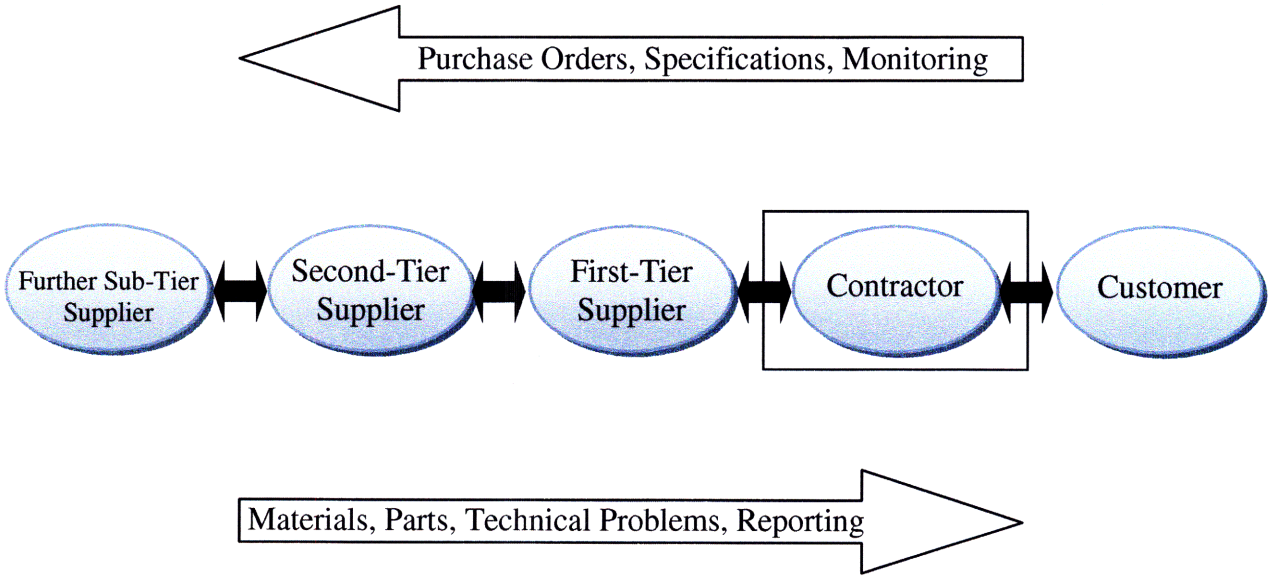


Figure 6.1.1: Simplified Supply Chain Diagram

6.1.2 Data Trending

Generally, dashboards that are used to monitor supplier performance show snap shots of performance at an instant of time. They often use color indicators to denote different levels of performance so that a manager can easily spot suppliers that went "red" or are mal-performing on a certain metric for that particular period (usually a month). Managers are sometimes given the option to "drill-down" and see further information such as the actual numbers measured for that metric. However, those numbers don't tell much on their own, and they can be used, at best, for damage-control. Rarely, if ever, do we see dashboards showing data trending of the used metrics over time. This, however, can be critical to anticipate problems bound to happen and try to prevent them instead of correct them after the fact.

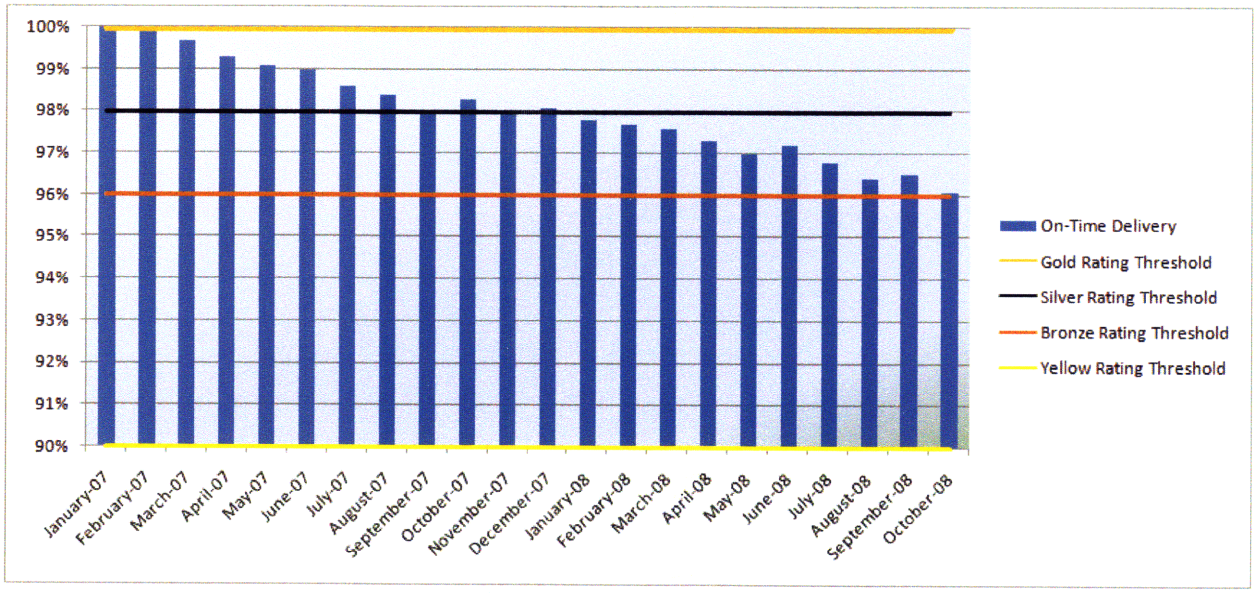


Figure 6.1.2: Data Trending of On-Time Delivery Metric

As an example, Figure 6.1.2 shows data trending of a supplier's on-time delivery over 22 months. As the manager looks at the this supplier's performance from January 07 to September

07 in a dashboard, he is not likely to be concerned since the color indicator still shows the supplier is rated as silver. Once again between January 08 and October 08, the dashboard will constantly show the supplier as bronze (which is still high performing but at the lowest level of high performance). However, as the data trending in the graph shows, the supplier performance has been constantly degrading and is expected after October 08 to dip down to the yellow rating if no preventive action is taken. While managers only see change of indicators once performance crosses a threshold, it is sometimes critical to monitor performance within those thresholds to prevent problems from occurring.

6.1.3 Statistical Process Control

Any complex process or system exhibits variation. Accordingly, supplier performance exhibits variation. However, detecting and explaining variation in performance is critical to determining the innocuous or conversely the adversarial effect of this variation on future performance. It is important to differentiate between two dissimilar cases of variation:

- Common-cause: are "white-noise" variations due to ever-present, minor, random change that are attributed to unknown causes. Such variations produce a stable, consistent pattern of variation over time.
- Special-cause: are variations due to significant change that may have "assignable" causes. Such variations do not have a consistent pattern over time, but a pattern that constantly changes (Kahn et al, 1996).

Monitoring suppliers' performance with a discerning eye as to common-cause or special-cause variation is important to predicting suppliers' future performance. For example, it might be

typical for a supplier to miss 15% ± 2% of delivery dates by a factor of 10% ±5% of lead time (Please note that the numbers are purely for demonstration purposes and carry no true value). So there is no need to set alarms to monitor this supplier if he's within this range. However if a supplier gets out of this range, it might be an indication of a future problem.

6.1.4 Root Cause Analysis of Supplier Position

Often suppliers provide signals of a problem waiting to happen. For example, a supplier might suddenly start making early deliveries, or decide to substitute a certain expensive material with another cheaper one, or even ask for cash early. These all can be indications of the supplier's difficult access to capital. A supplier's financial stability is closely tied to his/her ability to perform. Granted that a contractor might decide to help out the supplier for strategic reasons, discerning a supplier's financial health is a good indicator to predict a supplier's future performance. One leading indicator of this might be monitoring of sub-tier supplier ratings, such as their Dunn & Bradstreet credit rating and or their assessment by financial analysts if they are publically traded.

Other examples of root cause analysis of suppliers include any action that the contractor was suddenly required to do to secure performance and that he/she did not have to do previously. For instance if delivery suddenly needs constant expedited shipping to make it on time, or if the contract manager suddenly stopped receiving progress reports from suppliers and had to call the supplier weekly (when it was monthly previously) to ensure performance compliance. Though in these cases performance measures might well have been met, still it is likely that something is

going wrong at the supplier side and needs attention to figure out the root cause of the problem. So these again are indicators that can predict the suppliers' future performance.

6.1.5 Inspection of the Quality of Supplier Orders

Most large companies have some measures to rank their suppliers based on performance and to place them in categories of high or low-performing suppliers. Supplier rankings are typically based on a 12 month rolling average of supplier performance as noted by the company (for an example, see Boeing's SPM system in Section 4.2). Though these rankings are not bullet-proof and in some cases treat suppliers harshly by making their performance rating suffer due to a single error a year before, they are still good guidelines to determine the expected performance of suppliers. A company usually seeks to hire suppliers from the "high-performing" category, but in many cases has to opt for ones from the "low-performing" category as a last resort. As the percentage of critical orders made to "high-performing" suppliers decrease and that made to "low-performing" suppliers increase, it is likely that more problems are going to emerge along the way. So this could be an indicator for predicting performance.

6.1.6 Probing Intrinsic Changes within Suppliers

Intrinsic changes can happen to a supplier business which might affect performance. Such changes need to be probed to predict future performance. Examples include personnel attrition, especially of critical skills, and how training of new employees is accomplished. Another example is management change, whether due to a merger or acquisition or whether due to standard promotions. Yet another example is a change in the processes previously followed due

to Lean or other continuous improvement initiatives. Such intrinsic changes, if probed, can predict suppliers' future performance.

6.2 A System Dynamics Approach

John Sterman, director of MIT's System Dynamics group and one of the prominent leaders in the field, provided the following definition of system dynamics in his book "Business Dynamics: Systems, Thinking and Modeling for a Complex World":

> "*System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems*" (Sterman, 2000).

In this section I develop a system dynamics model that shows the relation among the four categories of cost, schedule, quality and technical performance as well as the factors that affect and are affected by them. The model enables us to understand the structure and dynamics of supply chains of production programs in Aerospace and Defense (A&D) companies and the critical factors that determine supply chain performance. I start by providing a brief overview of system dynamics elements and how to read a causal loop diagram for the benefit of readers who have not had previous exposure to the field.

6.2.1 Brief Introduction to System Dynamics Elements – How to Read a Causal Loop Diagram

Causal loop diagrams, like the ones shown in the next section, are an important system dynamic tool to represent feedback structures of systems. They allow identifying important feedbacks that are responsible for a certain problem. The main elements of the causal loop diagrams are the

following: variables, causal links, polarities, delays, loops (reinforcing and balancing), stocks, flows (inflows and outflows), valves and clouds. Variables are the entities connected to each other by arrows. These arrows represent causal effects between the variables and are called causal links. A polarity (positive or negative) is associated with each causal link showing the effect of the variable at the tail of the arrow to that on the spear of it. The polarity of causal links results in creating loops (or feedbacks) that are either reinforcing (or positive) and represented by "R" in the model, or balancing (or negative) and represented by "B". The clockwise and counterclockwise arrows around the "R" and "B" have the same direction as the feedback loop they represent. They just serve the purpose of making it easier for the reader to identify the loops being represented especially when the model is crowded with many overlapping loops.

The two parallel lines on the causal links designate delays; they illustrate that a change in an independent variable does not instantly result in a change in its dependent variable, but rather requires a certain delay in time. Stocks (or "levels") are accumulations and are designated by a rectangle suggesting a container accumulating the content of the stock. Stocks can only be changed by flows: an inflow, represented by a double-lined arrow pointing to the stock, adds contents to stocks, and an outflow, represented by a double-lined arrow pointing away from the stock, depletes contents of the stock. Flows have valves on them, represented by an hourglass shape, which control the rates of the flows, and finally clouds represent infinite sources and sinks (Sterman, 2000).

6.2.2 System Dynamics Models

In this section I show four causal loop diagrams, each focused on one of the four categories: cost, schedule, quality and technical. Using these diagrams, I identify the important factors that are

responsible for performance problems in each of the categories. Note that the models are developed for production programs in the Aerospace and Defense (A&D) industry. Therefore, they depict engineer-to-order type products that are not made to stock as inventory, but rather to be delivered to the customer per a specified demand. This simplifies the model since it does not include demand planning, inventory policies, development processes or maintenance.

Granted that the relationship between cost and profit depends on the type of contract (review Section 3.3: Types of Defense Contracts) and whether the contractor has full responsibility of costs or has them reimbursed plus a fee, my models depict the big picture governing that fact that in general an increase in cost (while keeping all other variables constant) eventually leads to a worse off company. Also note that all four models are repetitive at each level of the supply chain; they explain the factors affecting the contractors' performance as well as the sub-tier suppliers. The models were created using the Vensim 5.9 software tool.

6.2.2.1 Cost Focus

Figure 6.2.1 shows a causal loop diagram with a focus on cost. The model has four main reinforcing (positive) loops: first-time quality, skilled labor, growth and management change, as well as two main balancing (negative) loops: expediting and labor cost.

The reinforcing loops show the following dynamics:

- *First-Time Quality*: As total cost increases, profit decreases which decreases the company's financial stability. This leads to a pressure to cut costs, which increases the tendency to use cheaper substitute materials. This in turn increases defect introduction

rate which decreases the quality of the product and its rejection rate. This leads to a rework effort which ends up increasing cost even more.

- *Skilled Labor*: As total cost increases, profit decreases. This leads companies to reduce employee wages and benefits and perhaps lay off people. This urges employee to quit and so the layoff/quit rate increases. As skilled labor decreases, production knowledge and efficiency decreases which decreases the production capability and in turn increases cost further.
- *Growth*: As total cost increases, profit decreases which decreases the company's financial stability. This (after a certain delay) reduces the company's ratings (whether by the customer or Dunn & Bradstreet) which leads to less customer orders. As customer orders decrease, revenue decreases which decreases the company's access to capital. This decreases the company's tendency to grow which in turn decreases the plant capacity leading to a decreased production capability. Less production capability means higher costs, so here again cost is reinforced.
- *Management Change*: As total cost increases, profit decreases which decreases the company's financial stability. This reduces the company's ratings and thus the increases the need for change. So the rate of executives getting fired or who quit increases, which increases the hiring of new executives. As new executives increase, tendency to change increases, this does not sit well with employees and they get stressed, this in turn leads to attrition of employees and thus increases turnover which decreases the critical skills per project decreasing the production capacity and thus increasing cost.

The balancing loops show the following dynamics:

- *Expediting*: As total cost increases, profit decreases which decreases the company's financial stability. After some delay, this reduces the company's ratings, which leads to less customer orders. This decreases the order rate which reduces the backlog and increases the ability to make on-time deliveries. This leads to a decrease in schedule pressure and a decrease in expediting orders. This ends up decreasing total cost.
- *Labor Cost*: As cost increase, profit decreases leading to a smaller available budget for personnel. This decreases the hiring rate which decreases labor cost and in turn total cost.

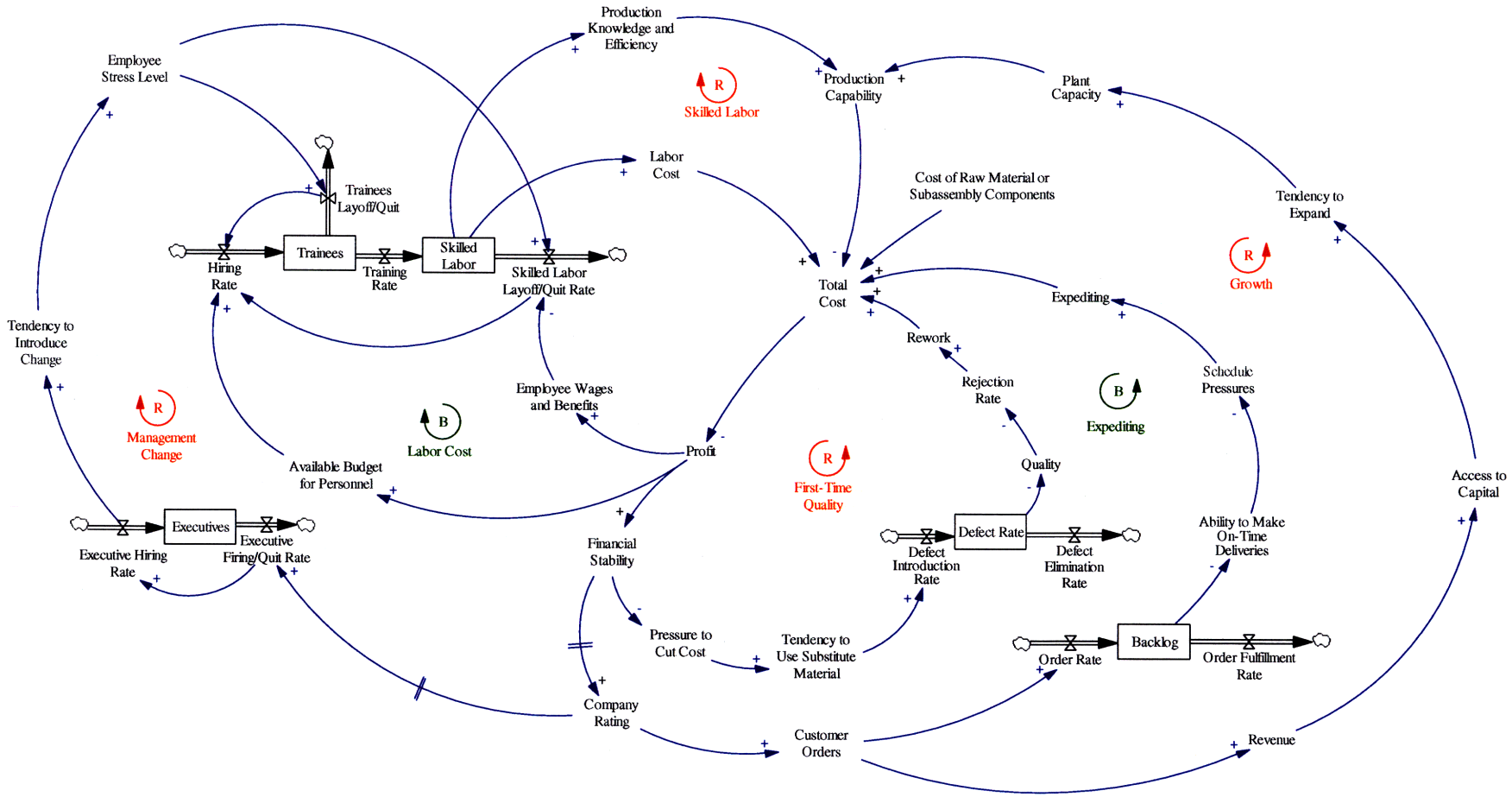


Figure 6.2.1: Cost Causal Loop Diagram

6.2.2.2 Schedule Focus

Figure 6.2.2 shows a causal loop diagram with a focus on schedule or on-time delivery. The model has three main reinforcing loops: financial stability and critical skills per project and two main balancing loops: backlog and rework.

The reinforcing loops show the following dynamics:

- *Financial Stability*: As on-time delivery increases, company ratings increase, this leads to higher customer orders, which increases sales, access to capital and overall financial stability. As financial stability increases there is less pressure to cut costs and use substitute materials. This in turn decreases defect introduction rate. As defect rate decreases, quality increases and rejection rate decreases. This leads to less rework and thus a better ability to make on-time delivery.
- *Critical Skills*: As on-time delivery increases, company ratings increase, which leads to higher customer orders, increasing sales, access to capital and overall financial stability. This leads to better employee wages and benefits, which helps retain skilled employees by decreasing their quit rate. As skilled labors quit rate decreases, the available critical skills per project increases which increases the chances of on-time delivery.
- *Employee Morale*: As on-time delivery increases, company ratings increase, which leads to higher customer orders, increasing sales, access to capital and overall financial stability. Higher financial stability leads companies to increase employee wages and salaries; this reduces the tendency of employees to ask for overtime. As overtime

decreases, employee stress level decreases, thus employee effectiveness increases, reinforcing the increase in on-time delivery.

The balancing loops show the following dynamics:

- *Backlog*: As on-time delivery increases, company ratings increase which increases customer orders and the overall order rate. This leads to an increase in backlog, which decreases the ability to make on-time deliveries and thus decreases on-time delivery.
- *Rework*: As on-time delivery increases, company ratings increase which increases customer orders and the overall order rate. This leads to an increase in backlog which increases schedule pressures and increases the tendency to "cut corners" and minimize testing and inspection. This leads to an increase in defect introduction rate. As defect rate increases, quality decreases increasing the rejection rate and rework. This increases the chances of a slip in schedule and thus decreases on-time delivery.

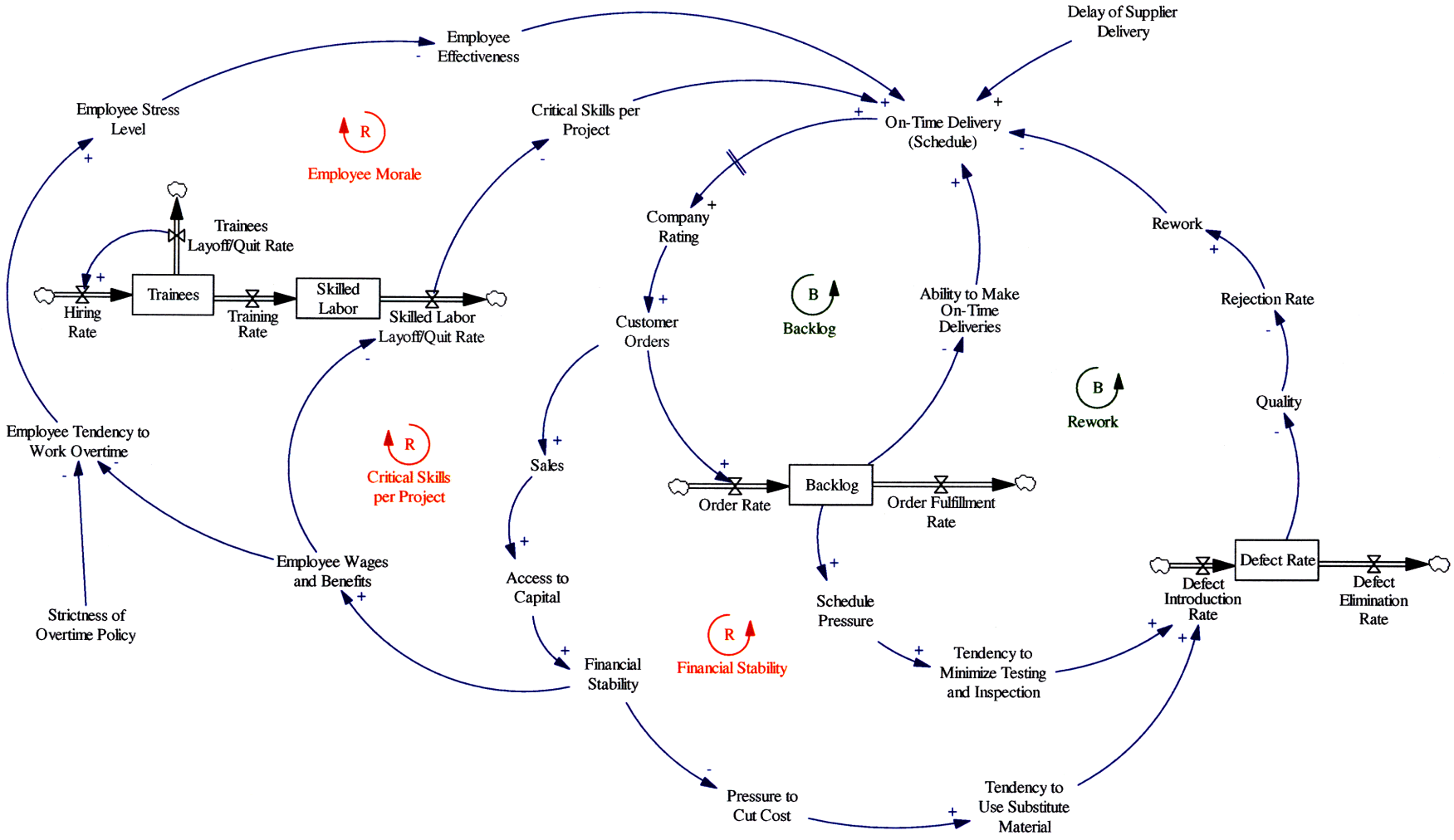


Figure 6.2.2: Schedule Causal Loop Diagram

6.2.2.3 Quality Focus

Figure 6.2.3 shows a causal loop diagram with a focus on quality. The model has two main reinforcing loops: process improvement and critical skills per project and two main balancing loops: plant uptime and minimizing inspection.

The reinforcing loops show the following dynamics:

- *Process Improvement*: As total quality increases, company ratings increase leading to higher customer orders. This increases revenue and in turn access to capital and financial stability. When a company is in a better financial position, investments in process improvements increase. This leads to an increase in the quality of followed procedures which increases total quality.
- *Critical Skills per Project*: As total quality increases, company ratings increase leading to higher customer orders and an increase in revenue. This makes the company have more access to capital and better financial stability which leads to better wages and benefits and skilled employee retention. This increases the critical skills per project which increases production effectiveness and increasing quality.

The balancing loops show the following dynamics:

- *Plant Uptime*: As total quality increases, company ratings increase leading to higher customer orders and a higher order rate. This increases backlog which increases schedule pressure. On a tight schedule, production companies tend to increase plant uptime,

however this leads to a decrease in the quality of equipment used and reduces total quality.

- *Minimizing Inspection*: As total quality increases, company ratings increase leading to higher customer orders and a higher order rate. This increases backlog which increases schedule pressure and the tendency to minimize testing and inspection. This leads to a decrease in the quality of procedures which decreases total quality.

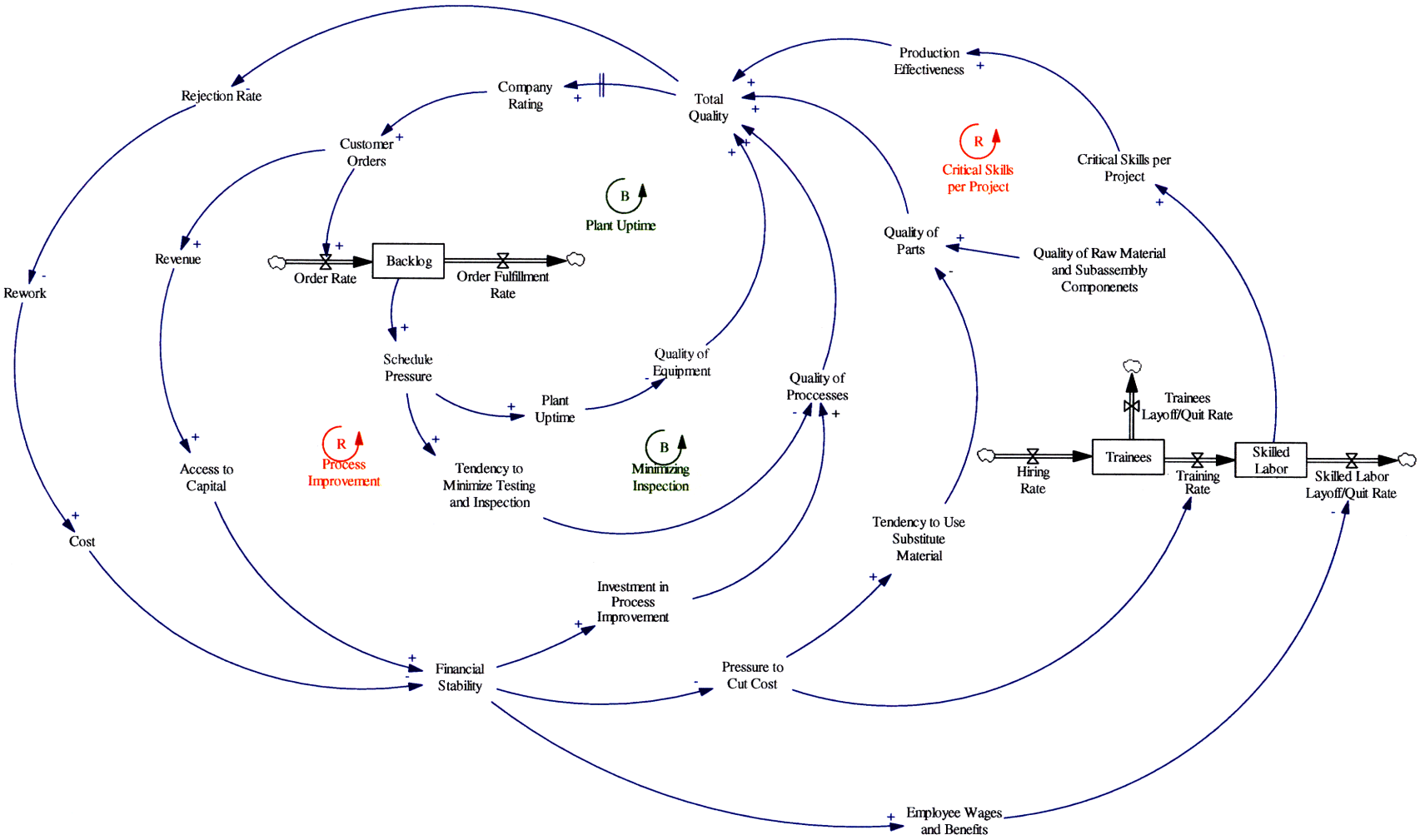


Figure 6.2.3: Quality Causal Loop Diagram

6.2.2.4 Technical Focus

Technical risks are minimal in the production phase since previous deliveries have been made, or at least prototypes have been developed and technical measures (such as weight, range, etc.) have been approved. Technical risks are much higher in developmental programs as they include engineering requirements.

However, Figure 6.2.4 shows a causal loop diagram with a focus on technical. Notice the exogenous variable "regulatory constraint" increasing the tendency to use substitute materials and therefore increasing technical risks. This variable represents government initiatives or regulations such as ROHS (Restriction of Hazardous Substances) which for example seeks to have lead-free environment. However, many products require lead as a critical element in their production so using a substitute material will create a technical risk. In fact, regulatory constraints are one of the most important factors affecting technical performance of production programs.

The model has three reinforcing loops: training, employee retention and research and development (R&D).

The reinforcing loops show the following dynamics:

- *Training:* As technical performance increases, company ratings increase which increase customer orders, sales, access to capital and overall financial stability. A financially stable company invests more into training which increasing training rate and the skilled

labor population. This leads to higher critical skills per project which decreases technical risks and increases technical performance.

- *Employee Retention:* As technical performance increases, company ratings increase which increase customer orders, sales, access to capital and overall financial stability. This leads to higher wages and benefits which, leads to the retention of skilled labor. This leads to an increase in critical skills per project which reduces technical risks and increases technical performance.
- *R&D:* As technical performance increases, company ratings increase which increase customer orders, sales, access to capital and financial stability. As financial stability increases, R&D funding increases leading to a higher tendency to perform thorough technical analysis. This leads to less technical risks and higher technical performance.

In the following section I determine the critical factors responsible for supply chains performance based on the results of the causal loop diagrams.

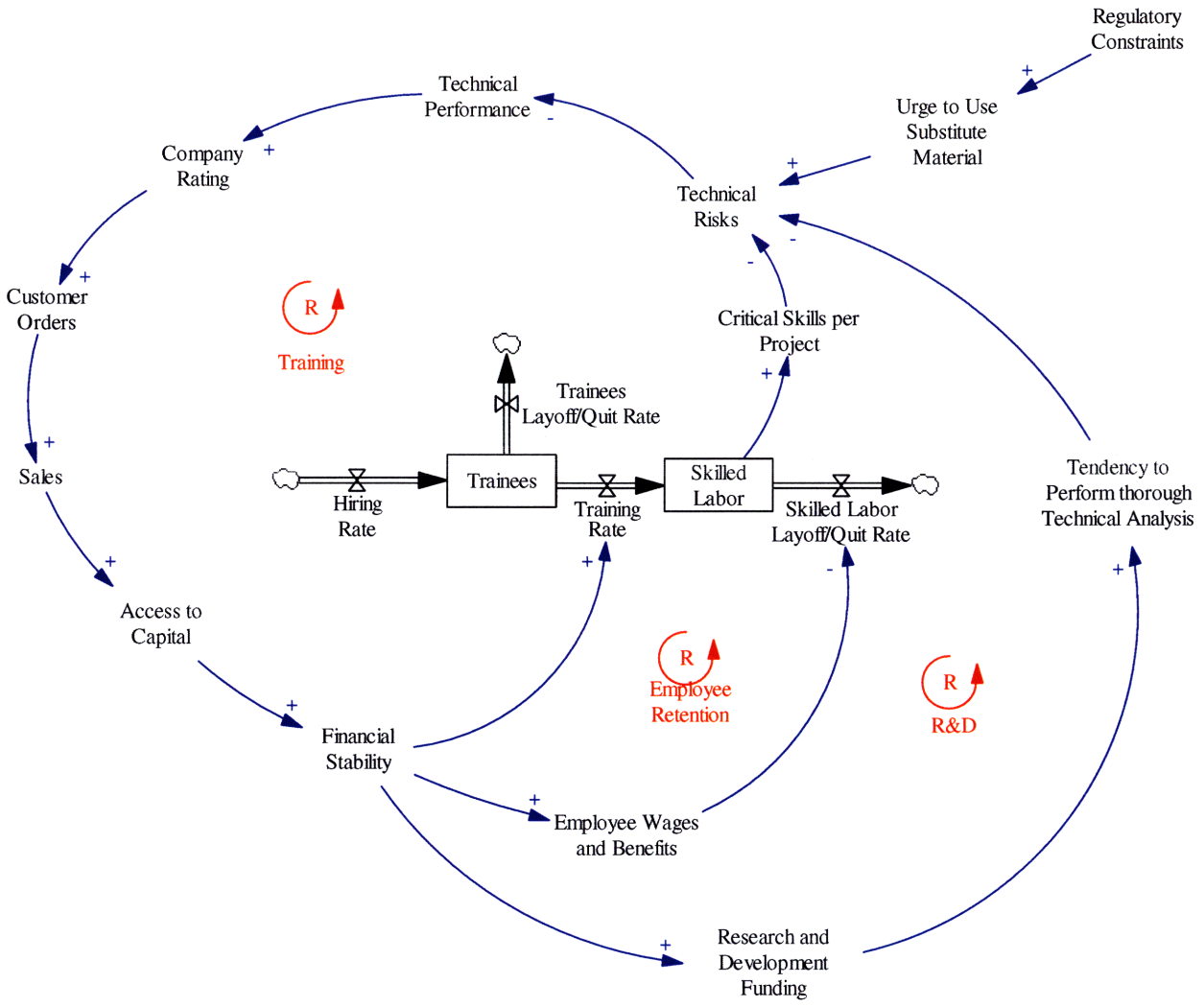


Figure 6.2.4: Technical Causal Loop Diagram

6.2.3 Critical Factors Responsible for Supply Chain Performance

As seen in Section 6.2.2, there are many factors responsible for supply chain performance problems in the four categories of cost, schedule, quality and technical. In fact the recurring feedback loops in the four categories show the criticality of these factors in determining performance. To sum up, Table 6.2.1 lists those critical factors responsible for supply chain performance, grouping them by type (people, process, product, business) and identifying the categories (cost, schedule, quality, technical) they primarily affect.

Table 6.2.1: List of Critical Supply Chain Performance Factors

		Factor	Cost	Schedule	Quality	Technical
People	1	Skilled Labor	x	x	x	x
	2	Critical Skills Per Project	x	x	x	
	3	Employee Retention (or Attrition)	x	x		
	4	Management Change	x	x	x	
	5	Employee Morale		x	x	
	6	Labor Cost	x			
Process	7	First-Time Quality (or Rework)	x	x	x	
	8	Backlog	x	x	x	
	9	Expediting	x	x		
	10	Inspection			x	
	11	Process Improvement			x	
	12	Training		x		x
Product	13	Plant Uptime		x	x	
	14	Research and Development				x
Business	15	Financial Stability	x	x	x	x
	16	Growth	x	x		

6.3 Comparing Predictive Metrics to "Reactive" Metrics

In this section I aim to show how predictive metrics and historical or "reactive" metrics measure the same things in completely different ways. While "reactive" metrics measure what *could* be measured based on historical data after-the-fact, predictive metrics measure the causal factors leading to performance before-the-fact, or what *should* be measured.

I do not, however, ignore the fact that measuring such factors can be challenging; nevertheless they are the drivers of the business and need to be closely monitored to guide preventive action. Consider for example that you are standing with your back to a wall and see your friend driving his car fast toward you. Let's say for the sake of illustration that there are shock-absorbers around you on the wall. You don't know at what speed he's driving to determine if you both will be safe due to the shock-absorbers or if he is going to crash and kill you. You don't even know if he sees the wall and you. What would you do? If nothing else you would move out of the way! Or try to wave, or if there's time call him and ask if he sees you and the wall. Most probably he does see you and the wall but guess what? His brakes aren't working!!

Now use the same example but substitute your friend by your supplier, the wall by bankruptcy, the car by the supplier's financial stability and the shock-absorbers by some cost-cutting procedures. You get the point. So even if it is hard to measure predictive metrics and tie them to exact numbers, it is critical to monitor them as a risk analysis in order to take preventive action.

Table 6.3.1 compares sample predictive metrics to "reactive" ones as each of them measures cost, schedule, quality and technical.

Table 6.3.1: Comparison of Sample Predictive and Reactive Metrics

Cost	
Predictive Metrics	**Reactive**
Skilled Labor	CPI[1]
Expediting	% Cost Increase
Labor Cost	Actual vs Quoted price
Management Change	Gross Sales Margin

Schedule	
Predictive Metrics	**Reactive**
Backlog	% of On-Time Deliveries
Critical Skills per Project	% Increase in Lead-Time
Employee Morale	SPI[2]
Expediting	% of On-Time start

Quality	
Predictive Metrics	**Reactive**
Skilled Labor	% of Defects
Employee Retention	Cost of non-conformance
Financial Stability	% Rejection
Plant Uptime	First Pass Yields

Technical	
Predictive Metrics	**Reactive**
Training	TPP[3]
Skilled Labor	KPP[4]
Research and Development	Prototype Testing Success rate
Financial Stability	Product Testing Success Rate

[1] Cost Performance Index
[2] Schedule Performance Index
[3] Technical Performance Plan
[4] Key Performance Parameter

Chapter 7 A PREDICTIVE METRICS FRAMEWORK

After identifying predictive indicators in Chapter 6 and understanding the structure and dynamics of the studied supply chain using a systems dynamics approach, in this chapter I seek to establish predictive metrics that would closely measure and determine the future status of the critical factors shown in Table 6.2.1 and thus predict future supply chain performance.

I develop a framework for selecting predictive metrics based on the type of program under study and the type of supplier delivering the product. In Section 7.1 I discuss supplier segmentation, in Section 7.2 I discuss program segmentation, in Section 7.3 I show the framework development and finally in Section 7.4 I present the framework and how to use it.

7.1 Supplier Segmentation

Due to the nature of the programs in the Aerospace and Defense Industry, contractors usually have to work with various suppliers ranging from a mom-and-pop shop across the street, to large multinational organizations. Monitoring suppliers differs vastly depending on the type of supplier.

Cox A. et al. (2000) developed what is known as the buyer and supplier "Power Matrix". This matrix classifies suppliers in four segments: Buyer Dominance, Supplier Dominance, Independence and Interdependence (see Figure 7.1.1). The matrix aims to clarify the situations in

supply chains where either the buyer or seller or both or neither have bargaining power that could be leveraged over the other party.

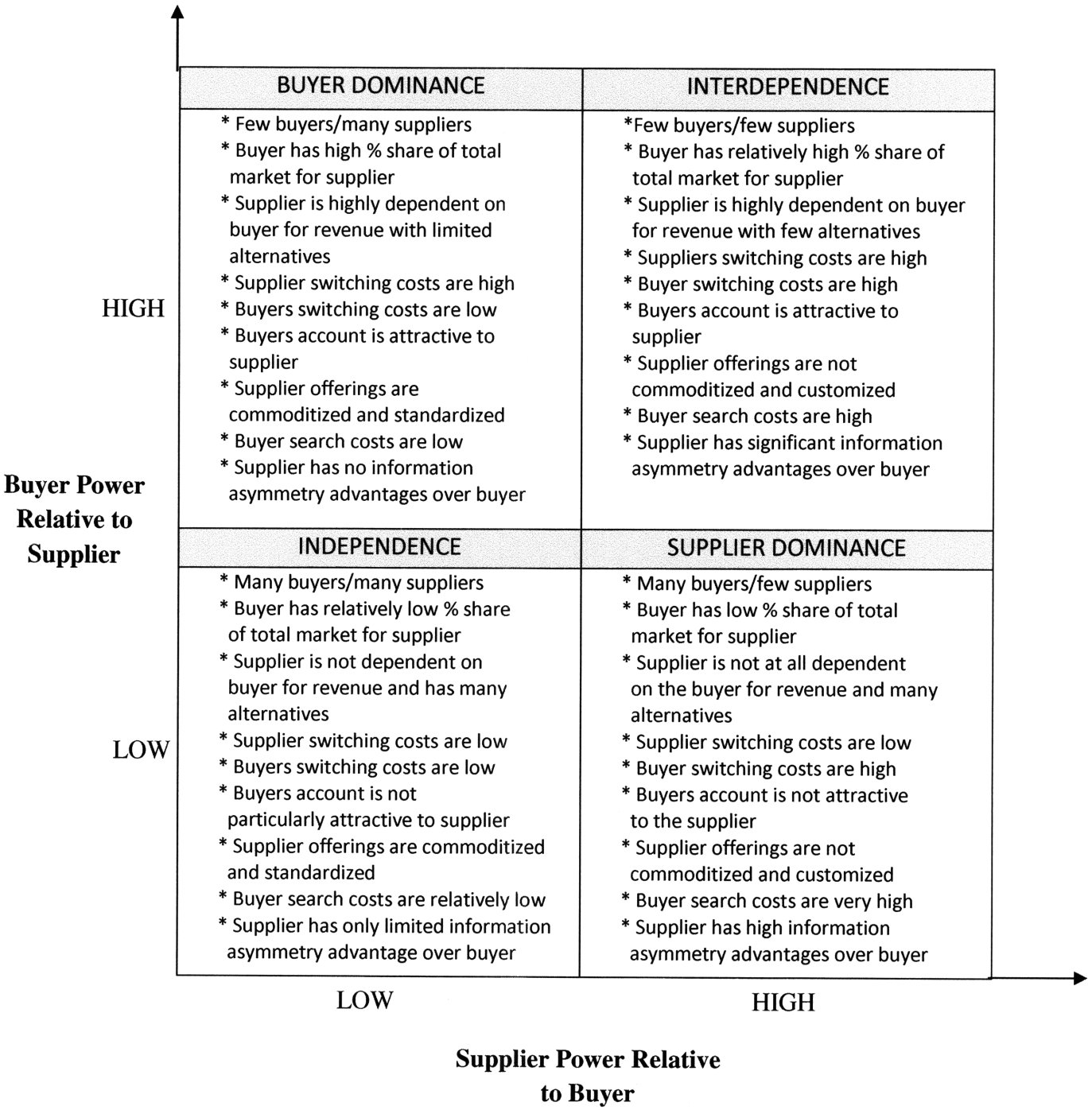


Figure 7.1.1: Buyer-Supplier Power Matrix
Adapted from (Cox, 2004)

The buyer-supplier relationship in each of the four segments is defined as follows:

Buyer Dominance: such relationships exist with suppliers who are dependent on the buyer for a significant portion of their business. In such cases the buyer has the power to negotiate favorable contracts. Another example applicable to the aerospace and defense industry is a supplier who provides custom-made components to a buyer, but who does not have the right to use the technology elsewhere since it belongs to the original buyer, whereas the supplier is not unique and the buyer can go elsewhere to get the same thing done.

Supplier Dominance: such relationships exist with suppliers who make specialized components and sell to multiple buyers. Such suppliers usually receive "sole-sourcing" as opposed to competitive bids since they have a unique technology or capability. In such cases a buyer has little or no bargaining power over the supplier.

Independence: such relationships exist with suppliers who manufacture standardized parts and sell to multiple buyers. Just as the supplier sells its components to multiple buyers, a buyer can also procure the same components elsewhere. In such cases no party has a major negotiating power.

Interdependence: such relationships exist with suppliers who, for example, make custom-made components using their own technologies, for a specific buyer. On one hand, the supplier depends on that buyer for a significant portion of his/her revenue, and on the other hand, the buyer depends on the supplier since the component is specialized and cannot be sourced elsewhere. This kind of a relationship is ideal for on-demand business since both parties have shared business interests (Roy, 2005).

For my framework, I used this "Power Matrix" to segment suppliers in the aerospace and defense industry and determine predictive metrics per category.

7.2 Program Segmentation

As programs differ by their objectives or business goals, so should the metrics that govern their behavior. Lapide (2006) developed the "Triangle" (see Figure 7.2.1) whose purpose is to align operational performance to business goals.

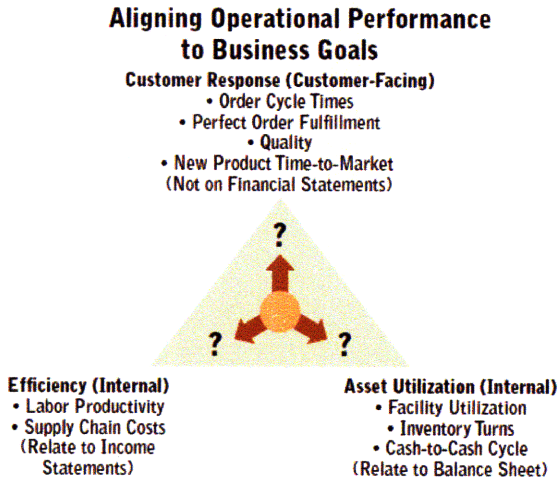


Figure 7.2.1: Aligning Operational Performance to Business Goals
Source: Lapide (2006)

The "Triangle" illustrates three different focuses: Customer Response, Efficiency and Asset Utilization. Customer Response focuses on the performance of customer-facing operations such as quality and order cycle time. Efficiency focuses on internal operations, such as labor productivity and cost, or "how well a supply chain converts inputs into outputs". Finally, Asset Utilization also focuses on internal operations, such as inventory turns, but targets "how effectively assets such as facilities and inventories are being used". Each company, or program in

our case, based on its strategy, should be positioned primarily in one of those areas. I segmented the programs in my framework based on this method, by finding the focus of the program and then tailoring its metrics to align with its strategy.

7.3 Framework Development Procedure

After segmenting suppliers and programs as described in sections 7.1 and 7.2, I explore the causal factors developed through the system dynamics model of section 6.2 to identify those that align with each of the segments. Table 7.3.1 shows the list of predictive metrics per program focus.

Note that in terms of our four performance categories, cost goes under "Efficiency" and all three of schedule, quality and technical go under "Customer Response" since these are customer-facing operations.

Also note that while some of the metrics do not normally belong to the categories they are in, they are predictive indicators of that category. For example, attrition is not normally a customer-facing operation, however, as attrition increases, the number of skilled workers decreases and the number of new hires increases. As skilled labor decreases, it is likely that quality will decrease as well. But quality is a "Customer Response" measure, so attrition becomes a predictive metric for the "Customer Response" category. Similar logic exists for the metrics in Table 7.3.1 and they have all been derived from the feedback loop structures of the system dynamics model of Section 6.2.2.

Table 7.3.1: Predictive Metrics per Program Focus

Customer Response	Efficiency	Asset Utilization
Attrition	Attrition	Attrition
Backlog	Critical Skills Per Project	Backlog
Company Rating	Expediting	Critical Skills Per Project
Critical Skills Per Project	Financial Stability	Growth
Employee Morale	Labor Cost	Management Change
Expediting	Management Change	Plant Uptime
Financial Stability	Overtime	Process Improvement
Management Change	Skilled Labor	Training
Overtime	Use of Substitute Material	
Plant Uptime		
Process Improvement		
Skilled Labor		
Testing and Inspection Procedure		
Training		
Use of Substitute Material		
Wages and Benefits		

I follow the same procedure and determine predictive metrics per supplier type. The results are shown in Table 7.3.2.

Table 7.3.2: Predictive Metrics per Supplier Type

Buyer Dominance	Supplier Dominance	Interdependence	Independence
Attrition	Company Rating	Attrition	N/A
Backlog	Expediting	Backlog	
Company Rating	Financial Stability	Company Rating	
Critical Skills Per Project	Growth	Critical Skills Per Project	
Employee Morale	Management Change	Employee Morale	
Expediting	Testing and Inspection Procedure	Expediting	
Financial Stability	Use of Substitute Material	Financial Stability	
Growth	Wages and Benefits	Growth	
Labor Cost		Labor Cost	
Management Change		Management Change	
Overtime		Overtime	
Plant Uptime		Plant Uptime	
Process Improvement		Process Improvement	
Research and Development		Research and Development	
Skilled Labor		Skilled Labor	
Testing and Inspection Procedure		Testing and Inspection Procedure	
Training		Training	
Use of Substitute Material		Use of Substitute Material	
Wages and Benefits		Wages and Benefits	

Note that the "Buyer Dominance" category includes all the predictive metrics that were deemed crucial for supply chain performance in section 6.2. That is because when the buyer (or contractor) is in power, he/she can enforce measuring those metrics on the supplier. A similar case exists with the "Interdependence" category. In this case both the buyer and supplier have equal power and are working strategically together so it is likely that they both can negotiate using metrics on each other. On the contrary, in the "Supplier Dominance" section, since the buyer has no power over the supplier, he/she is unlikely to be able to get the supplier to provide internal information such as attrition, backlog, or plant uptime, and the only source of information is what is publicly available such as company ratings as shown in the table. Finally the "Independence" category holds no metrics. That is because in this case neither the buyer nor the supplier cares about the other's performance and both can take their business elsewhere at no cost. The "Independence" category includes suppliers of standard parts, such as cables, resistors or attenuators, that have virtually no lead time and are widely available. Though, in principle, the same metrics used in the "Supplier Dominance" category can be used in the "Independence" category since they are publicly available, however, I believe that might add unnecessary overhead since if a supplier defaults, the buyer can get the same parts elsewhere that same day.

To sum up, the buyer can only negotiate favorable terms when he/she has equal or superior power over the supplier, so the buyer should seek to have the majority of his/her suppliers in these two regions and work closely with them for optimal performance.

7.4 A Framework for Predictive Metrics

After identifying the predictive metrics for each program and supplier type, I now find the intersections of each program focus with each type of supplier. The results are shown in the predictive metrics framework in Table 7.4.1.

The framework identifies which predictive metrics best anticipate supply chain performance within each category. However, it is up to the contractor to determine to which category he/she belongs when dealing with each supplier. While supplier segmentation is straight forward, program focus has some nuances. Lapide (2008) addresses this in his follow-up article and states that while each company primarily lies in one of the three corners of the "Absolute Triangle" based on industry or to "play in the game", there are smaller "Relative Triangles" within each absolute one (see Figure 7.4.1) and each company has to find its location within that triangle based on what drives its business competitively, i.e. what sets them apart from their competitors.

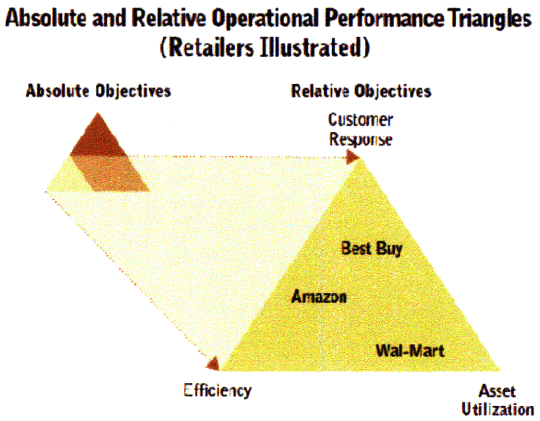


Figure 7.4.1: Absolute and Relative Operational Performance Triangles
Source: Lapide (2008)

Table 7.4.1: Predictive Metrics Framework

	Customer Response	Efficiency	Asset Utilization
Buyer Dominance	Attrition Backlog Company Rating Critical Skills Per Project Employee Morale Expediting Financial Stability Management Change Overtime Plant Uptime Process Improvement Skilled Labor Testing and Inspection Procedure Training Use of Substitute Material Wages and Benefits	Attrition Critical Skills Per Project Expediting Financial Stability Labor Cost Management Change Overtime Skilled Labor Use of Substitute Material	Attrition Backlog Critical Skills Per Project Growth Management Change Plant Uptime Process Improvement Training
Supplier Dominance	Company Rating Expediting Financial Stability Management Change Testing and Inspection Procedure Use of Substitute Material Wages and Benefits	Expediting Financial Stability Management Change Use of Substitute Material	Growth Management Change
Interdependence	Attrition Backlog Company Rating Critical Skills Per Project Employee Morale Expediting Financial Stability Management Change Overtime Plant Uptime Process Improvement Skilled Labor Testing and Inspection Procedure Training Use of Substitute Material Wages and Benefits	Attrition Critical Skills Per Project Expediting Financial Stability Labor Cost Management Change Overtime Skilled Labor Use of Substitute Material	Attrition Backlog Critical Skills Per Project Growth Management Change Plant Uptime Process Improvement Training
Independence	N/A	N/A	N/A

Therefore, while I believe the aerospace and defense industry lies in the top corner (Customer-Response), different companies would need to find their location within that top part, probably per program type. Based on their position, they will have to denote different weights to predictive metrics, and thus define on which ones they want to far exceed their competition and on which ones they are okay with being on par with the competition.

Furthermore, metrics should have thresholds, or some levels to measure against and these should be determined based on the each specific situation.

Finally, Figure 7.4.2 shows the concept of operation of my predictive metrics model. Both the program focus and supplier type determine which predictive metrics to use. There's also the actual supply chain operation which feeds changes to predictive metrics. These in turn are fed to the system dynamics model to determine the root cause factor and corrective action. This changes the supply chain operation and the loop goes on to keep enhancing performance.

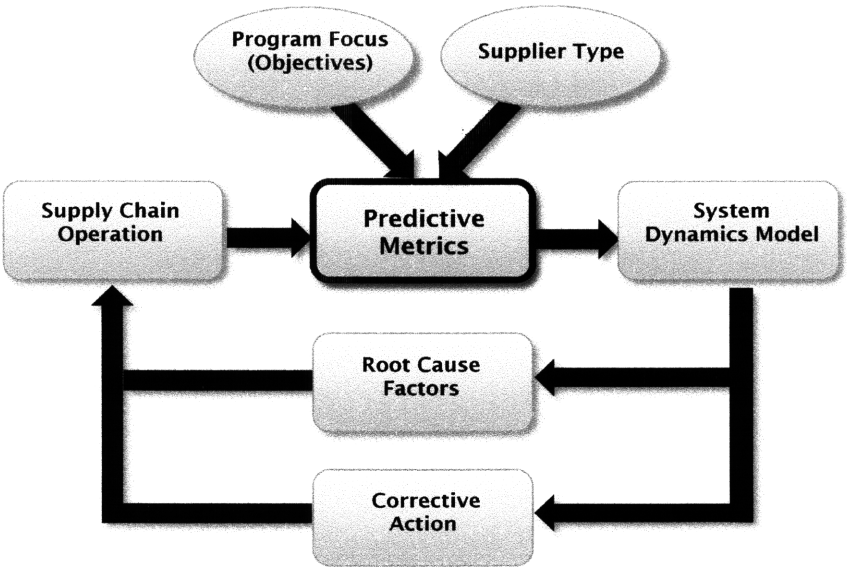


Figure 7.4.2: Concept of Operation of Predictive Metrics

Chapter 8 ILLUSTRATION OF FRAMEWORK APPLICATION

In this chapter I show which categories of the framework are applicable to each of the three case study programs described in Chapter 5

Davenport (2008) recently conducted a survey of almost 2,500 cross-industry manager and found that customer-response is by far the top priority. This case is even more prominent in the Aerospace and Defense (A&D) industry as seen in the CAPS Research benchmarking report in Section 3.4. In fact, most of the A&D programs focus on quality and technical performance (both Customer Response) then schedule and finally cost. This is conventionally the case due the nature of product implementation and the ability of an error to risk lives. Nonetheless, due to the current economic crisis, A&D companies have started to pay more weight to cost as seen in Section 3.5.

Furthermore, depending on the type of defense contract and whether the contractor is fully responsible for costs or has them reimbursed, he/she will place different emphasis on cost. However, overall, the A&D industry is primarily focused on customer-facing operation. So "Customer Response" is the program focus to be used in the predictive metrics framework.

8.1 Handheld Radio

The Handheld radio program is a firm fixed-price type contract (see Section 5.1 for an overview of the Handheld Radio Program). This means that the contractor is fully responsible for any costs

incurred (see Section 3.3). While Boeing in general is in the top corner of Lapide's (2008) "Triangle" (see Section 7.2), focusing on "Customer Response", the Handheld radio is located at the bottom of the "Relative Triangle" playing in the game of "Customer Response" but focusing within it on cost or "Efficiency". So there should be stronger emphasis on the "Efficiency" predictive metrics within the "Customer Response" category. These are marked with an asterisk (*) in Table 8.1.1.

To decide in which segment each supplier lies, and thus decide which category of the framework to use, the following guidelines should be employed:

1. Does Boeing provide over 60% of the supplier's revenues? => Buyer Dominance
2. Does Boeing and the supplier work strategically together with each party providing a product/service to the other? => Interdependence
3. Is the Supplier providing a unique product to many buyers, Boeing being one of them? => Supplier Dominance
4. Is the item purchased a commodity or non-specialized item, such as resistors, cables etc, where many suppliers exist and many buyers? => Independence

Finally, Table 8.1.1 shows the predictive metrics to be used for this program for optimal performance. The asterisks (*) represent stronger emphasis on those variables.

Table 8.1.1: Predictive Metrics for the Handheld Radio and the Military Aircraft Programs

	Customer Response
Buyer Dominance	Attrition*
	Backlog
	Company Rating
	Critical Skills Per Project*
	Employee Morale
	Expediting*
	Financial Stability*
	Management Change*
	Overtime*
	Plant Uptime
	Process Improvement
	Skilled Labor*
	Testing and Inspection Procedure
	Training
	Use of Substitute Material*
	Wages and Benefits
Supplier Dominance	Company Rating
	Expediting*
	Financial Stability*
	Management Change*
	Testing and Inspection Procedure
	Use of Substitute Material*
	Wages and Benefits
Interdependence	Attrition*
	Backlog
	Company Rating
	Critical Skills Per Project*
	Employee Morale
	Expediting*
	Financial Stability*
	Management Change*
	Overtime*
	Plant Uptime
	Process Improvement
	Skilled Labor*
	Testing and Inspection Procedure
	Training
	Use of Substitute Material*
	Wages and Benefits
Independence	N/A

8.2 Military Aircraft

The Military Aircraft program is a firm fixed-price type contract (see Section 5.1 for an overview of the Military Aircraft Program). This means that the contractor is fully responsible for any costs incurred (see Section 3.3). While Boeing in general is in the top corner of Lapide's (2008) "Triangle" (see Section 7.2), focusing on customer response, the Military Aircraft is located at the bottom of the "Relative Triangle" playing in the game of "Customer Response" but focusing within it on cost or "Efficiency", just like the Handheld Radio program.

To decide in which segment each supplier lies, and thus decide which category of the framework to use, the same guidelines described in the Handheld Radio illustration should be used (see Section 8.1). Finally, the predictive metrics to be used are the same as those of the Handheld Radio program described in Table 8.1.1.

8.3 Missile Defense System

The Missile Defense program is a fixed-price-incentive type contract (see Section 5.3 for an overview of the Missile Defense Program). This means that the contractor shares losses and savings up to a certain ceiling price (see Section 3.3). While Boeing in general is in the top corner of Lapide's (2008) "Triangle", focusing on customer response, the Missile Defense Program is still located at the top of the "Relative Triangle" focusing even more on "Customer-Response".

To decide in which segment each supplier lies, and thus decide which category of the framework to use, the same guidelines described in Section 8.1 should be used. Finally Table 8.3.1, shows the predictive metrics that closely anticipate supply chain performance for this program.

In fact it was indicated the Missile Defense program has one major supplier and Boeing works very closely with him/her on a strategic relationship where both parties monitor each other's performance and provide guidance when needed. This type of relation places the supplier in the "Interdependence" segment which is ideal for best performance. This, coupled with the correct design of the supply chain to focus on "Customer Response" and continuous risk analysis, are primary reasons, I believe, for this program's outstanding performance.

Table 8.3.1: Predictive Metrics for the Missile Defense Program

	Customer Response
Buyer Dominance	Attrition Backlog Company Rating Critical Skills Per Project Employee Morale Expediting Financial Stability Management Change Overtime Plant Uptime Process Improvement Skilled Labor Testing and Inspection Procedure Training Use of Substitute Material Wages and Benefits
Supplier Dominance	Company Rating Expediting Financial Stability Management Change Testing and Inspection Procedure Use of Substitute Material Wages and Benefits
Interdependence	Attrition Backlog Company Rating Critical Skills Per Project Employee Morale Expediting Financial Stability Management Change Overtime Plant Uptime Process Improvement Skilled Labor Testing and Inspection Procedure Training Use of Substitute Material Wages and Benefits
Independence	N/A

Chapter 9 CONCLUDING REMARKS

9.1 Conclusion

Organizations cannot afford to have anymore performance "surprises", especially bad ones (Davenport, 2008). Predictive metrics provide early warnings of problems and early indications of successful project completion. While an ideal goal of predictive metrics is to provide one comprehensive model that can be applied across an organization, this is difficult to achieve especially with large, complex corporations like aerospace and defense ones where widely different types of suppliers are hired and different products are manufactured. Instead, a few simple critical predictive metrics that are aligned with the business strategy are provided based on the focus of the program and the type of supplier.

It is worth noting that predictive metrics do not eliminate the need for historical data altogether, but actually find smarter ways to probe what is needed of them. Predictive metrics are positioned in the present with an eye toward the future. For example, historical data of performance measures, such as percentage of defects or percentage of on-time-deliveries, is needed to perform data trending and predict future performance (See Section 6.1.2). Moreover, collecting such data, over many years, is important to determine the existence and value of lag effects for some variables that influence the four performance categories (cost, schedule, quality, and technical).

It is also critical to note that in order for a company to achieve success, its strategy and supply chain should be aligned. Furthermore, metrics, and in this case, predictive metrics should also be in alignment with the strategy and supply chain. A company needs to know where its competitive

edge lies: in which areas they want to excel and in which areas they are fine being on par with their competitors. Having the business strategy, the supply chain and the metrics disjoint is recipe for failure.

As seen in the framework, buyers should, as much as possible, try to maintain a long term relation with the suppliers (as opposed to having several arms-length transactions) and select them primarily from the "Interdependence" category. This is beneficial for both sides. Moreover, contractors should seek to never source a critical component to a supplier in the "Supplier Dominance" region, as the buyer has least control in this region and is at the mercy of the supplier.

The developed framework is intended to be used along the entire supply chain. Thus, similar to the way the contractor monitors his/her first-tier suppliers, those first-tier suppliers should monitor their sub-tier suppliers as well.

It is worth noting that metrics are not bound to stay intact forever. In fact while I believe the metrics I provided closely reflect the studied supply chain, in today's world, business models keep changing and metrics need to change as well to reflect the current situation.

9.2 Future Research

I see three areas directions for future research based on this thesis:

1) *Predictive Metrics for Development Programs:* This thesis was only focused on production programs, that is, programs that have already passed the development stage and have started receiving orders. A direction for future research is developing a framework for development programs. This is likely to include engineering requirement documents, technical reviews, etc.
2) *Predictive Metrics for the Maintenance Supply Chains:* This thesis was focus on the manufacturing part of the programs. A possible direction for future research is developing a framework for the maintenance supply chains. This is likely to include the environment of operation of the product, causal variables affecting product downturn, etc.
3) *Introduction of Software:* This thesis specifies which predictive indicators are key to programs, however, I do not include a systematic approach for analyzing data to measure those indicators. A direction for future research can include developing and employing software to allow analyzing data and measuring predictive indicators in an integrated manner. Predictive Analytics is a current effort in this area.

REFERENCE LIST

CAPS Research. (2009). Aerospace and Defense Industry: 2009 Supply Management Performance Benchmarking Report.

Cizmeci, D. (2005). An Examination of Boeing's Supply Chain Management Practices within the Context of the Global Aerospace Industry. MIT Engineering Systems Division Thesis.

Chan, F. T. S., & Qi, H. J. (2003). An Innovative Performance Measurement Method for Supply Chain Management. Supply Chain Management: An International Study, Vol. 8(3), pp.209-230.

Cokins, G. (2009). Performance Management: Integrating Strategy Execution, Methodologies, Risk and Analytics.

Cox, A. et al (2003). Supply Chain Management: A Guide to Best Practice, Financial Times/Prentice Hall. London.

Cox, A. (2004). The art of the possible: relationship management in power regimes and supply chain. Supply Chain Management, Vol. 9(5), pp. 346-356.

Crow, K. (2001). Product Development Metrics. DRM Associates. [WWW Document], URL http://www.npd-solutions.com/pdmetrics.html

Davenport, T. H. (2008). The Rise of Analytical Performance Management. White Paper, Harvard Business Digital and SAS.

Defense Logistics Agency. (2002). Contract Types. [WWW Document]. URL http://www.dtc.dla.mil/dsbusiness/Info/contracts1.htm

Gunasekaran, A., Patel, C., & McGaughey, R. E. (2004). A Framework for Supply Chain Performance Measurement. International Journal of Production Economics, Vol. 87(3), pp. 333-347.

Hammer, M. (2001). The Agenda: What Every Business Must Do to Dominate the Decade Crown Business.

Huang, S.H., & Keskar, H. (2007). Comprehensive and Configurable Metrics for Supplier Selection. International Journal of Production Economics, Vol. 105(2), pp. 510-523.

Kahn et al. (1996). Statistical Process Control Methods for Expert System Performance Monitoring. Journal of the American Medical Informatics Association, Vol. 3(4), pp. 258-269 .

Kaplan, R.S., & Norton, D.P. (1992). The Balanced Scorecard: Measures that Drive Performance. Harvard Business Review, Vol. 70(1), pp. 71-79.

Kemp, R. (2003). What Do You Know About Your Critical Suppliers? Paper presented at the 88th Annual International Conference Proceedings, Nashville, TN.

Kleijnen, J. P. C., & Smits, M. T. (2003). Performance Metrics in Supply Chain Management. Journal of the Operations Research Society, Vol. 54 (5), pp.507-14.

Lapide, L. (2000). What About Measuring Supply Chain Performance. AMR Research. ASCET, Vol. 2(15), pp.297-289.

Lapide, L. (2006). MIT's SC2020 Project: The Essence of Excellence. Supply Chain Management Review, Vol. 10(3), pp.18-24.

Lapide, L. (2008). The Operational Performance Triangles. Supply Chain Management Review, Insights, pp.6-7.

Lehmann, D.R. & O'Shaughnessy, J. (1982). Decision criteria used in buying different categories of products. Journal of Purchasing and Materials Management, Vol. 18(1), pp.9–14.

Roy, S. (2005). World Class Supply Chains in the Computer Industry. Submitted to the Engineering Systems Division towards ESD.920: Research in Engineer Systems Design, Massachusetts Institute of Technology

Standard & Poor's. (2009). Industry Surveys: Aerospace & Defense.

Sterman, J. (2000). Business Dynamics: Systems, Thinking and Modeling for a Complex World. Irwin Mcgraw-Hill.

Supply Chain Council (2008). Supply-Chain Operations Reference-model, Version 9.0.

The Boeing Company. (2009-a). About Us. Retrieved April 10, 2009, from Boeing: http://www.boeing.com/companyoffices/aboutus/

The Boeing Company. (2009-b). Business Units. Retrieved April 10, 2009, from Boeing: http://www.boeing.com/biz_unit.html

The Boeing Company. (2009-c). Supplier Performance Measurement in BEST. Retrieved April 27, 2009, from Boeing: http://www.boeing.com/companyoffices/doingbiz/supplier_portal/Launcher/RunCourse.htm

Wilson, E.L., 1994. The relative importance of supplier selection criteria: a review and update. International Journal of Purchasing and Materials Management. Vol. 30(3), pp. 35–41.

APPENDIX A – Questionnaire for Program Managers

This appendix shows the main questions I asked the program managers of the three Boeing programs while I interviewed them. The questions are shows below:

1. What is the profile of each of the programs' supply chains? Who are the key players and how many are there?
2. Where is the material flow and the information flow in the SC?
3. What are the set objectives in each of cost, schedule, quality, technical? Are there standard guidelines?
4. What percentage of the products is sent back for repair? How often?
5. How do you select suppliers? Based on what criteria?
6. How often do you change suppliers? Based on what?
7. How often do you monitor suppliers? How?
8. Is there a program-wide supplier monitoring system or is each supplier monitored independently?
9. How often do you get purchase orders? What is the process for getting them through?
10. How large are typical purchase orders?
11. What are the current measures for evaluating suppliers? Is there any comprehensive framework?
12. What is the average lead time for product delivery?
13. Are there regular changes or upgrades to the current production? If so how often do they happen and how far do they affect the SC?
14. What percentage of product production is outsourced versus made in-house?
15. What would you like to see in our predictive metrics?
16. Any suggestions?

APPENDIX B – Supplier Survey

This survey was sent to suppliers of the three Boeing Programs. It was administered and completed online using surveymonkey.com, but the copy shown in this section is the printable version. Note that the names of the programs have been concealed for the sake of confidentiality.

MIT-Boeing Predictive Metrics for Supply Chains Project

1. Information About Your Company

I am an MIT graduate student working on a project with Boeing titled "Predictive Metrics for Supply Chains". The goal of the project is to find a set of predictive measures that would anticipate the program performance early enough to make corrective action effective.

The purpose of this survey is to gather information on how Boeing suppliers measure their internal performance and the performance of their suppliers.

Please note that Boeing will not be told of your specific answers and your response will be kept anonymous and used solely for the purpose of the study.

If you would like to share a standard evaluation form that you use for your internal performance management or for managing your suppliers please send it to lindahay@mit.edu.

*** 1. Which Boeing program does your group support?**

○ [redacted]
○
○

*** 2. What is the name of your company?**

2. Measurment of Internal Performance

*** 1. What criteria do you use to track and evaluate your internal performance in the areas of:**
- Cost (e.g. Cost Performance Index (CPI), Rework)
- Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))
- Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))
- Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):

Cost
Schedule
Technical
Quality

MIT-Boeing Predictive Metrics for Supply Chains Project

2. How often do you review your internal performance?

- Weekly
- Bi-Weekly
- Monthly
- Yearly
- Other (please specify)

3. On what criteria are you evaluated by Boeing in the areas of:
- Cost (e.g. Cost Performance Index (CPI), Rework)
- Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))
- Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))
- Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):

Cost _____
Schedule _____
Technical _____
Quality _____

3. Measurement of Supplier Performance

*** 1. About what percentage of your critical suppliers are determined by Boeing as sole sources?**

- 0%
- 25%
- 50%
- 75%
- 100%

MIT-Boeing Predictive Metrics for Supply Chains Project

*** 2. What criteria weighs into selecting your suppliers that are not predetermined by Boeing as sole sources? (Check all that apply)**

- ☐ History of working with supplier
- ☐ Cost
- ☐ Delivery
- ☐ Quality
- ☐ Other (please specify)

*** 3. What criteria do you use to track and evaluate your suppliers' performance in these areas:**
- Cost (e.g. Cost Performance Index (CPI), Rework)
- Schedule (e.g. Schedule Performance Index (SPI), Critical Path Length Index (CPLI))
- Technical (e.g. Technical Performance Plan (TPP), Key Performance Parameters (KPP))
- Quality (e.g. Percentage of Defects, Process Capabilities (Cp, CpK)):

Cost
Schedule
Technical
Quality

4. Final Thoughts

1. Do you use any predictive indicators (such as staffing, change in management, funding ability, etc..) to anticipate your suppliers' future performance as opposed to using only backward-looking indicators?

- ○ No
- ○ Yes (please specify)

2. Any Comments?

If you would like to share a standard evaluation form that you use for your internal performance management or for managing your suppliers please send it to lindahay@mit.edu.

Thanks for your time and your valuable input!