DISSERTATION

RAND

Improving Air Force Purchasing and Supply Management of Spare Parts

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This research provides the Air Force with a methodology with which to evaluate various strategies for improving the procurement of spare parts and an example use of the methodology for F100 engine parts. Using exploratory analysis techniques and system dynamic modeling a structural analysis of the interaction of these changes is studied leading to a better understanding of the effectiveness of the various supplier management policies. This includes identifying those policy levers most effective in improving various measures of interest. Although this research provides a broad structure across objectives and alternatives that are often "stove-piped" between organizations, it also points out where additional research is needed to improve understanding certain relationships (e.g. the impact of contract length on quality), their functional forms and their parameters. Some parameters may require alteration for other kinds of parts in other applications. Thus, the methodology highlights achieving a broad macro understanding of purchasing management policy.

This dissertation shows that policy and organizational changes in the PSM process have the potential to improve effectiveness while maintaining or lowering costs. It has also demonstrates that a system dynamic model used with can provide an important contribution to defining, discussing, and understanding the complex interactions between policy levers and outcome measures particularly in enhancing PSM efficiency and effectiveness. The model serves as a helpful aid to facilitate discussion with all levels of personnel. By facilitating an in-depth exploratory analysis into the interaction of the PSM policy levers, insights were gained into how the PSM process interacts that were previously not well understood. Moreover, by populating the model with a specific data set, broad policy recommendations were formulated that when implemented should improve the support provided to the F100 engine at a reduced overall cost.

Preface

This dissertation is submitted to the RAND Graduate School in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Policy Analysis. It was funded by Project Air Force and is part of the overall analytical support provided under the Project AIR FORCE study, "Designing, Implementing, and Evaluating a Purchasing and Supply Management (PSM) Demonstration for Engines," sponsored by AF/IL-I and SAF/AQC.

This research provides the Air Force with a methodology with which to evaluate various strategies for improving the procurement of spare parts and an example use of the methodology for F100 engine parts. Using exploratory analysis techniques and system dynamic modeling a structural analysis of the interaction of these changes is studied leading to a better understanding of the effectiveness of the various supplier management policies. This includes identifying those policy levers most effective in improving various measures of interest. Although this research provides a broad structure across objectives and alternatives that are often "stove-piped" between organizations, it also points out where additional research is needed to improve understanding certain relationships (e.g. the impact of contract length on quality), their functional forms and their parameters. Some parameters may require alteration for other kinds of parts in other applications. Thus, the methodology highlights achieving a broad macro understanding of purchasing management policy.

The findings of this study should be of interest to policy makers in the acquisition and sustainment communities as well as those interested in the application of System Dynamic Models and exploratory analysis techniques.

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Acknowledgments

I would like to thank all who gave their time and talents in an attempt to educate the author on the intricacies of the Purchasing and Supply Management process and how to best capture this process in a system dynamic model. While much of this information has been captured in this document, any omissions or errors that remain as well as the assertions and conclusions drawn regarding the efficacy of the various programs are the sole responsibility of the authors.

I would like to offer thanks to by dissertation committee, Dr. Bart Bennett, Dr. Nancy Moore, and Dr. Susan Gates, for providing me with invaluable guidance and feedback. They were instrumental to my success, remaining supportive and flexible at all times, despite my often challenging schedule constraints.

I would also like to thank HQ USAF/Il-I and SAF/AQC for supporting this research effort as well as all the personnel at the Okalahoma City Air Logistics Center who freely gave of their time to ensure that this research had access to information on the actual processes used at the ALC and data regarding the parts purchased to support the F100 engine. In particular, Mary Chenoweth, RAND analyst was instrumental in helping me understand the various Air Force databases and how they could be used to provide input data for this effort. Her support and guidance is much appreciated.

Finally, I would like to thank my wife and children, who helped maintain my focus and for providing support when progress was difficult. This work would not have been possible without their assistance.

List of Abbreviations

Abbreviation	Definition
AFB	Air Force Base
AFMC	Air Force Material Command
AFMC/LG	Air Force Material Command Directorate of Logistics
AFMC/PK	Air Force Material Command Directorate of Contracting
ALC	Air Logistics Center
ALT	Administrative Lead Time
AMC	Acquisition Method Code
AMSC	Acquisition Method Suffix Codes
BO	Backorder
DLA	Defense Logistics Agency
DoD	Department of Defense
FFP	Firm Fixed Price
FSC	Federal Supply Classification
FY	Fiscal Year
GAO	General Accounting Office
IPT	Integrated Product Team
ISO	International Organization for Standardization
LRT	Logistics Response Time
MC	Mission Capable
MTBR	Mean Time Between Requirement
NIIN	National Item Identification Number
NMCS	Not Mission Capable Supply
NSN	National Stock Number
OC-ALC	Oklahoma City ALC

PLT	Production Lead Time
PSM	Purchasing and Supply Management
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference Model
SPO	System Program Office

1. Introduction

"You cannot meddle with one part of a complex system from the outside without the almost certain risk of setting off disastrous events that you hadn't counted on in other, remote parts. If you want to fix something you are first obliged to understand ... the whole system..."

Lewis Thomas, 1974 p. 90

Often, the Air Force has difficulty acquiring spare parts in the correct quantity and quality at a reasonable cost when needed, and this affects the readiness rates of its weapon systems. While a variety of improvements have been proposed and tested, the Air Force lacks an objective methodology to estimate the effect and interaction of various changes in its Purchasing and Supply Management (PSM) process. Currently, anecdotal evidence and a limited number of demonstrations are the only support for decisions regarding the preferred organizational design, procurement process, and contract structure. These decisions tend to focus on only one policy handle at a time (e.g. reducing suppliers or increasing contract length) rather than looking at a combination of policies and their synergism. This research provides a methodology with which to evaluate various combinations of strategies for improving the procurement and management of spare parts. Exploratory analysis techniques and system dynamic modeling provide the capability to perform a structural analysis of the interaction of these changes, and can lead to better decisions regarding the effectiveness of the various supplier management policies.

The Need for Change

The Air Force's mission is, "to defend the United States and protect its interests through aerospace power."[1] The successful completion of this mission requires support, which is constrained by the level of funding and manpower provided. While cost and other efficiency concerns exist, they are not the primary drivers of the design of the military's processes and procedures. The primary focus has been on the effectiveness of the system to defend the United States from its enemies, particularly the Soviet Union during the Cold War. With

[1] United States Air Force, homepage, October 1, 2002, www.af.mil/welcome.shtml (as of November 8, 2002).

the end of the Cold War, there is no longer a need to support a large military force, nor is there the ability and need to sustain a large industrial complex.[2] Accompanying a reduction in the size of the military is a shift in the nature of the companies that support the Department of Defense (DoD). In the past, the DoD represented the primary customer for many industries such as information technology or advanced materials. Today the private sector dominates many of these industries. This shift is clearly stated in the testimony to Congress of Frank Fernandez, Director of the Defense Advanced Projects Research Agency who testified that, "...the explosion of commercial information, transportation, and biological technologies has made the DoD [and the Air Force] a market-place *follower* rather than the world technology *leader* it has been in the past."[3] To fit into an increasingly commercial environment any transformation must include changes in how the military acquires and supports its weapon systems, to include heavier reliance on commercial practices and equipment.[4]

These two forces, the shrinking of the military and an increased need to operate in a more commercial environment have led to an increased importance in the effectiveness and efficiency of the military support systems. However, the business operations of the Department of Defense must adhere to political constraints imposed by Congress to include improving the social welfare of the nation in general,[5] as well as work within the traditional economic market forces of supply and demand. Consequently, the best course of action in this complex environment is not always clear.

During the last decade, the Defense Department implemented a number of alternative concepts to improve the efficiency of its business practices to include acquisition reform, an increased focus on competition and outsourcing commercial activities, and a variety of small initiatives within each individual military service in an attempt to make the military operate more like a

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[2] National Defense Panel, *Transforming Defense: National Security in the 21st Century*, Arlington, VA, December 1997, p. v.

[3] Fernandez, Frank, Director Defense Advanced Research Projects Agency, Statement Before the Subcommittee on Emerging Threats and Capabilities, Committee on Armed Services, United States Senate, April 20, 1999.

[4] National Defense Panel, *Transforming Defense: National Security in the 21st Century*, Arlington, VA, December 1997, p. 75.

[5] Examples of how the DoD is tasked to improve the social welfare of the nation include the requirements to support economic growth by doing business with small businesses and to improve the vitality of inner cities by purchasing goods and services from inner-city businesses where possible. The "Small Business Reauthorization Act of 2000," Public Law 106-554 passed December 14, 2001 updated many of the small business regulations and extended several programs designed to support small businesses. Online at: http://www.navysbir.com/106-554-SBIR.pdf. (as of January 24, 2003).

commercial enterprise. These have met with varying degrees of success due to the complex nature of the Defense Department's business practices (or for that matter the practices of any large enterprise) and a lack of detailed financial data to measure the success of these individual initiatives. This paper proposes a quantitative approach to measuring the impact of PSM improvements that not only provides specific recommendations for future initiatives, but also serves as a framework within which to conduct the debate regarding the effects of PSM related change initiatives. This dissertation uses modern modeling techniques and software to help better understand the interaction amongst the various PSM policy levers and objectives, which provides an encompassing, common structure and a point of reference for analyzing key aspects of the problem of how the Air Force should design its PSM activities.

Logistical Support Systems Are In Transition

In general, Air Force PSM processes (like most other Air Force processes) have evolved over time through incremental change in ad hoc ways.[6] Currently, the roles of the various participants such as supply, transportation, or maintenance are all separate and distinct. Supply personnel determine which parts to stock and in what quantities while transportation personnel are responsible for the movement of these parts between the various components of the logistics system. When a part is broken, another part of the organization with its own personnel determines how and when to repair items. Adding to the complexity of this structure is the fact that other support areas such as contracting, engineering, or financial management have their own functional structures and guidelines for operation. This bureaucratic structure, while useful for the control and management of personnel, is not aligned to the process of buying and sustaining parts needed to support a weapon system. The final facet of the problem, the interaction between the government and suppliers from the commercial market place, is handled by contracting personnel who due to legal and procedural constraints must maintain a degree of independence. This includes the activities of requirements determination and task execution.

To address the discontinuities in the current design, the DoD to include the Air Force is in the process of transforming its logistics system.[7] The focus of

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[6] The United States Commission on National Security/21st Century, *Road Map for National Security: Imperative for Change*, Final Draft Report, January 31, 2001, p. 63.

[7] Gansler, Jacques S., Under Secretary of Defense (A&T) statement to the U.S. Senate Armed Services Readiness Subcommittee, April 26, 2000. Online at www.acq.osd.mil/ousda/testimonies/sasc_oral.htm (as of November 12, 2002).

this transformation is to improve the support provided while reducing the cost of procuring items by better utilizing existing assets. Complicating this transformation is the increasing age of many military systems and their corresponding increased demand for spare parts and repairs. Within the Air Force community, there has been a variety of initiatives proposed to improve the procurement process from centralization to standardizing procedures.[8] However, many of these initiatives have competing and/or complementary effects. For example, efforts to decrease contract administrative costs by using a firm-fixed price contract or simplified contracting procedures for small purchases may also increase individual part or total ownership costs. Alternatively, the stronger ties with suppliers promoted in strategic sourcing may also facilitate improved supply chain integration and management. It is evident then, that the true interactive effect of these efforts is not well understood.

To improve the spares supply process used to support the warfighter, the Air Force initiated a Spares Campaign.[9] This campaign selected eight key initiatives (Table A) to modernize the spares process to support Expeditionary Air Force (EAF) operations, change the financial management practices, improve the spare's requirements estimating process, provide accountability and authority for spares performance, and exploit relevant commercial capabilities.[10] Selected from a pool of ideas, each of these initiatives were chosen based upon their potential impact on meeting Air Force goals and their ability to be implemented within 12-15 months.[11] Each of the eight key initiatives focuses on a different aspect of the supply chain with the overall goal of providing the greatest improvement while minimizing the potential for conflict between the initiatives due to the multiple objective nature of this problem.

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[8] A brief overview of the various alternative strategies proposed to improve the PSM practices of both the government and commercial enterprises can be found in Appendix D.

[9] Rukin, Karen L., "Up Front: Changing Air Force Logistics," *Air Force Journal of Logistics*, Vol. XXV, Number 4, Winter 2001, p. 35.

[10] Zettler, Michael, "Improving Spares Support for the Warfighter," Air Force Installations and Logistics (HAF/Il) briefing given 31 October 2001.

[11] Mansfield, Robert E., Jr., "Improving Spares Availability - The Spares Campaign Plan," Headquarters Air Force Director, Supply briefing given April 24, 2001.

Table A: Spares Campaign Initiatives[12]

Initiative	Objective	Focus
Change Depot Level Reparable Structure	Set stable prices and allocate costs to responsible Commands	Stabilize and pass all costs to end consumer
Improve Spares Budgeting	A single consolidated budgeting process for spares and consumable items	Internal budgeting and planning
Improve financial Management	Track execution of Weapon System support against approved plan and budget	Better total cost visibility and accountability
Improve Demand & Repair Workload Forecasting	Improved forecasts; enhanced supply and workload planning capabilities	More accurate forecasting of requirements
Establish Virtual Single Inventory Control Point	Centralized processes for consistent execution and enforcement of the spares buy and repair allocation	Create central point of control for supply chain
Align Supply Chain Management Focus	Provide Supply Chain Managers with authority and accountability for the supply chain	Improve global focus and authority of supply chain managers
Expand Role of Regional Supply Squadron	Make Regional Supply Squadrons standard for support	Improve distributive networks
Adopt Improved Purchasing & Supply Management	Reduced purchase costs, improved product quality and delivery by implementing PSM practices	Improve link between Supplier Network and Air Force

The focus of this dissertation is the final initiative, "Adopt Improved Purchasing & Supply Management (PSM)," which uses innovative strategies and business practices to reduce delivery times, purchase costs, and improve product quality.[13] This PSM initiative is intended to ensure that the relationships between suppliers and the Air Force are structured correctly given the nature of the parts being purchased, the size of the current supply base, and the criticality of the parts to the overall performance of the Air Force's weapon systems. The current process of procuring each part (National Stock Number) individually can lead to sub-optimal arrangements in the short term such as having a variety of types and lengths of contracts for similar items or multiple contracts with the

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[12] Zettler, Michael, "Improving Spares Support for the Warfighter," Air Force Installations and Logistics (HAF/IL) briefing given 31 October 2001.

[13] Zettler, Michael, "Improving Spares Support for the Warfighter," Air Force Installations and Logistics (HAF/IL) briefing given 31 October 2001.

same vendor.[14] The inclusion of the PSM initiative in the Spares Campaign attempts to address the lack of coordination and control from an enterprise perspective that is currently lacking in the Air Force.[15]

Within the PSM initiative, the Air Force is currently testing several alternatives using a variety of pilot projects at various locations.[16] One of those demonstrations provides much of the data needed to develop a model of the existing spares process and serves as a benchmark to compare the results of this dissertation. While the effects of individual changes on a particular unit or location may be known through the use of demonstrations, the efficacy of these initiatives for global implementation and the nature of the interaction of the various programs is not clearly defined or discussed in a single demonstration. This dissertation attempts to provide an overarching analysis and complements the current Air Force demonstration activities. Although there is no one clearly "best" PSM strategy for all goods and services, and significant differences exist between various alternatives in their ability to achieve individual goals. The selection of a strategy or mix of strategies for implementation is sensitive to the actual goods and services and supply market being modeled and should consider the finding of this research as an indication of what is possible with each strategy. The actual results achieved when implementing the findings of this or any other "design study" will vary due to changes in the implementation process, the personnel implementing the various alternatives, as well as the goods and services and their supply market being analyzed.

Research Approach

Real world processes are complex, interactive systems in which policies do not always cause linear results. Traditional analytical methods attempt to statistically identify a cause and effect relationship between parameters and then link those actions together to form a model of the process (Figure 1). A more robust modeling technique, such as system dynamic modeling, is helpful to

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[14] In supporting the Air Force's efforts to improve their PSM practices, RAND has analyzed Air Force spending over the past several years and identified multiple areas of potential improvement. Moore, Nancy, Cynthia Cook, and Charles Lindenblatt, "Using a Spend Analysis to Help Identify Prospective Air Force Purchasing and Supply Management Initiatives: Summary of Selected Findings," Santa Monica, Calif.: RAND, forthcoming RAND research, 2003.

[15] Rukin, Karen L., "Up Front: Changing Air Force Logistics," *Air Force Journal of Logistics*, Vol. XXV, Number 4, Winter 2001, p. 35.

[16] For details on the current Air Force PSCM efforts see: Tinka, Marie and Scott Correll, " Improving Warfighter Readiness Through Purchasing and Supply Chain Management (PSCM) Transformation," HQ AFMC, PSCM IPT briefing, June 2003.

better understand the interactions between the various components of the system when the assumptions of traditional models do not hold (Figure 2).

Figure 1. Traditional Approach to Modeling

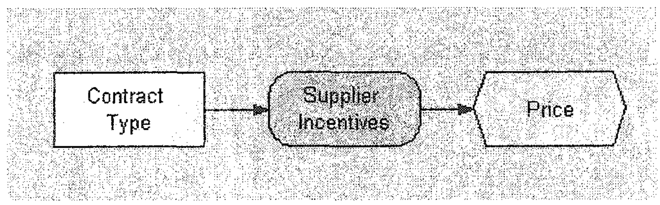
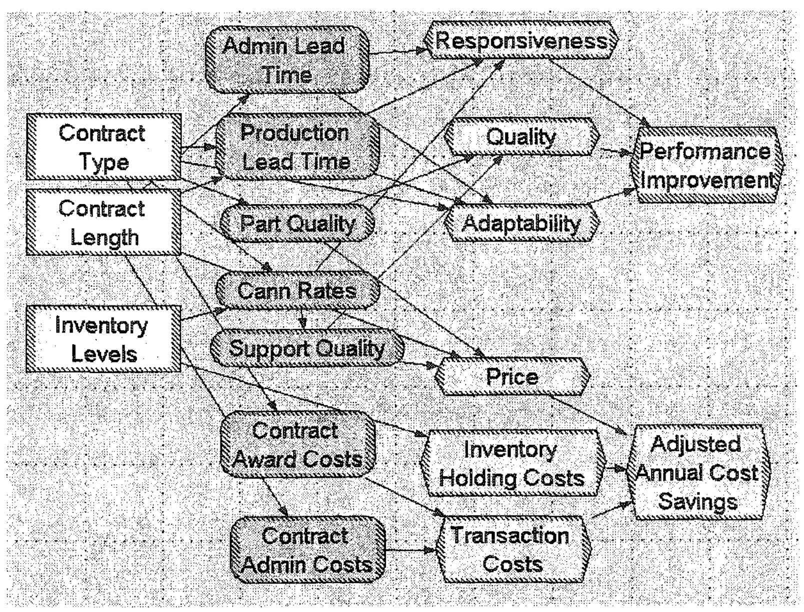


Figure 2: System Dynamic Modeling Approach



By modeling different combinations of various policy levers associated with PSM, the effect of these changes can be better understood. Figure 2 presents a graphical example of how several of these levers link to the end objectives of performance improvement and adjusted annual cost savings. Unlike the traditional linear approach, shown as the lines in Figure 1, a system dynamic model explicitly captures the complex structural interaction of the process. Figure 2 illustrates that many of the PSM policy levers do not directly affect the desired outcomes such as improved quality, but instead, work through intermediate steps that should be included in a complete representation of the process. Although these intermediate relationships are conceptually or theoretically determinable, the functional forms to represent them and their parameterization for particular cases may not be clear. The goal of this research is primarily to provide a means for getting our arms around the whole problem, with some details left for future work.

This dissertation uses an Analytica® based exploratory model to conduct a quantitative analysis regarding the anticipated effect of alternative PSM strategy combinations. It is argued that without capturing the complete network of effects, it is not possible to understand the relationship between changes to policy levers and the effect of these changes on measures of interest. Specifically, this research has three objectives: Quantify the discussion, Conduct the Exploratory Analysis, and develop recommendations for changes to the current processes. Each of these objectives are now discussed in more detail.

1. *Quantify the discussion*

It is hypothesized that system dynamic modeling techniques can be used to develop a useful and realistic model of key aspects of the procurement process to include not only the interactions between the various policy levers but their notional effect on measures of interest. While in the past many policy change proposals were based on an individual case study or analogy to an existing business policy. To fully understand the dynamics of the spares procurement process a quantitative model is needed. Using System Dynamic Modeling techniques, a quantitative model is developed of the process of purchasing spare parts. This graphically based model helps stakeholders understand the interrelationships of the various policy levers so that they can debate these interactions using a consistent point of reference. Unlike previous modeling techniques, which required the development of custom computer code,[17] system dynamic models stress the need for visually representing the interactions so that the structure of the model is no longer a "black box" but a useful asset in and of itself.[18] The ability to include feedback loops, where the output from one portion of the model affects future iterations of the system is an additional benefit of a system dynamic model that is not present in many causal models developed using statistical techniques. This ability to "solve" the model repeatedly for successive time periods allows the system to respond to stimulus, and then return to a new equilibrium. By examining this rebalancing process, one can

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[17] Keating, Edward G, *Government Contracting Options: A Model and Application*, Santa Monica, Calif.: RAND, MR-693-AF, 1996.

[18] Morgan, M. Granger, and Max Henrion, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge, UK: Cambridge University Press, Cambridge, 1990, p. 259.

often make observations regarding the stability of the system that are not possible in studying only the equilibrium position.

2. *Conduct Exploratory Analysis*

In addition to being a useful tool to visualize how elements of the system interact, a system dynamic model can be used to conduct exploratory analysis. This has two beneficial features. First, it helps determine the key levers and assumptions present in the model that are critical to achieve a desired set of final results. Thus, critical areas can be identified and flagged for further examination to ensure they are modeled correctly, whereas areas that are not critical need not be modeled in such detail.

Secondly, exploratory analysis includes the consideration of many "demonstrations," to better determine how certain policy configurations will affect the outcomes of the system. This analysis helps policy makers better understand the cause-and-effect relationships in the PSM system, and thereby aid in the development of arguments for or against proposed changes to the existing system. Because these computer simulations are much more inexpensive than real world demonstrations, they can be used to test a multitude of different scenarios in a very short time. By examining a large number of different scenarios, the robustness of a given set of alternatives can be examined ensuring that the solution selected for implementation is not only close to optimal, but robust in relation to changes in the real world environment that may or may not be perfectly captured in the model.

3. *Recommend Changes to Current Process*

Finally, as with any real world analysis, the results of this study suggest the most beneficial PSM policies for the given data set of F100 engine parts analyzed. These findings, as well as the lessons learned from the real world demonstrations currently being conducted at all three Air Force Air Logistics Centers, should help shape the future structure and procedures used to support Air Force systems. With up to $20-30 billion in cost reductions and performance improvements possible, the potential for savings from these changes is significant.[19]

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19 Taibl, Paul, "Logistics Transformation: DoD's Opportunity to Partner with the Private Sector," Business Executives for National Security, October 1999. Online at www.bens.org/tail%5Fbrief2.html (as of November 12, 2002).

The quality of this analysis, like any model-based effort, is constrained by the ability to first identify those links that represent the PSM process and to then accurately capture them in functional forms. Unlike current PSM analysis, which is based primarily on individual case studies with no attempt to directly link the results to the policy change, the results of this analysis will depend greatly on the assumptions made regarding the form, data, and structure of the system. This dissertation will explicitly state and document these assumptions. Documenting the process gives policy makers a better understanding of how PSM works and the uncertainties in which it operates. It also serves to further the discussion at the policy level on which processes and interactions are appropriate to measure and with how much weight.

Scope of the Analysis

As stated earlier, the overall objective of Air Force logistics is to support the weapon systems operated by the end customer. Meeting this objective requires the successful completion of myriad tasks to deliver adequate levels of support. In addition to the purchase of spare parts, proper transportation networks are needed, as are sufficiently trained maintenance personnel to repair weapon systems properly. The successful operation of this logistics network is beyond the scope of any one study, and to fully understand its operation, it must be broken into components that are more manageable. This research looks at one part of the overall spares procurement process: the relationship between the Air Force and its suppliers. By examining the effect of a variety of PSM policy levers on performance measures (Table B), a robust design can be determined to provide spare parts support to Air Force operational units.

Table B: Model Components

Policy Levers	Measures of Improvement
Number of Suppliers	Responsiveness
Number of Contracts per Supplier	Quality
Supplier Development	Adaptability
Inventory Levels	Price
Contract Length	Inventory Holding Costs
Joint Forecasting	Transaction Costs
Performance Measures	Personnel Costs
Integrated Product Teams	

Within this limited scope, the data used to populate the model was extracted from the F100 engine maintained by the Oklahoma City Air Logistics Center at Tinker Air Force Base, Oklahoma. This dissertation selected this data set primarily because of its availability through a real world demonstration of PSM being conducted in parallel with this research. The Air Force selected the F100 for the demonstration not only because of the availability of data, but for the fact that this system contains a mixture of parts[20] that can demonstrate many of the levers of PSM as they apply in the Air Force.[21] A representative subset of the F100 to include all types of parts, contract arrangements, and failure patterns is used to test the system dynamic model.

While the actual findings will be limited to a specific sub-set of F100 items, they suggest areas of potential improvement for other parts with similar characteristics. As a proof of concept demonstration of the efficacy of system dynamic modeling, the most significant finding of this research is the ability or inability of system dynamic modeling techniques to add substance to the discussion of how to improve the PSM process. It is the explicit link between various policy levers and outcome measures of interest that has been lacking in

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[20] In addition to the thousands of parts that are common to other engines and managed by the Defense Logistics Agency, the Air Force manages over 3,000 F100 unique parts ranging from electronic components and small hardware items, to complex assemblies that serve as the core of the engine itself.

[21] Mansfield, Robert and Darryl Scott, "PSM Pilot Discussion", briefing by AF/IL-I and SAF/AQC to PSM pilot team via video teleconference, November 19, 2001.

past studies. The model can easily be adapted with minimal modification to other sets of input data to produce detailed findings for other commodities.

While the design of the desired process can be determined using this and other analytical techniques, the fact that changes to the PSM process must be implemented by human beings,[22] who do not fully execute the design or fail to adapt to the new system, should not be overlooked. Creating the optimal operating environment in which to execute the design represents an additional challenge not included in the scope of this project, and training on proper procedures and developing detailed implementation plans is needed overcome implementation issues.[23]

While primarily focused on design, this research also indirectly considers execution issues. For example, an adequate design that is robust to execution errors would be preferred to a perfectly designed system that is sensitive to minor execution errors and is likely to never operate properly. Thus, the "optimal" system design must consider and account for minor variations in the parameters of the model and errors in the execution (amount ordered, order time, etc). Ignoring this human element of the problem could lead to academic solutions that cannot be effectively implemented in the real world. Exploratory analysis is a useful approach for specifically including operational uncertainty into the basic problem structure, which to a certain extent can also be a proxy for execution problems. This can help ensure that the findings are robust and are more likely to be successfully translated from the drawing board to the real world.

Finally, many legal and regulatory barriers must be addressed for the full implementation of many PSM best practices to be successful. These include legislative requirements for Core and 50/50 workloads to remain at Air Force Logistics Centers,[24,25] small business regulations,[26] and the current procurement

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22 Markus, M. Lynne, "Lessons from the Field of Organizational Change," *Journal of Strategic Performance Measurement*, April/May 1998, pp. 36-45.

23 Baudin, Michel, "Six Sigma and Lean Manufacturing," Manufacturing Management & Technology Institute. Online at http://www.bettermanagement.com/Library/Library.aspx?LibraryID=4318&a=8 (as of November 12, 2002).

24 U.S. Code Title 10, Section 2464, *Contracts: competition requirements*, January 21, 1998 states that DoD activities should maintain the government-owned and operated core logistics capability necessary to maintain and repair weapon systems and other military equipment needed to fulfill national strategic and contingency plans.

25 U.S. Code Title 10, Section 2466, *Limitations on the Performance of Depot-level Maintenance of Materiel*, December 28, 2001 states that no more than 50 percent of the depot maintenance funds for a given fiscal year may be spent for depot maintenance conducted by non-federal personnel.

and organizational procedures and regulations. This model takes a longer-term view of the change process and assumes that these barriers are amenable to change, without explicitly describing the change process. While the potential for improvement is great, all of these factors must be considered when actually implementing the commercial version of PSM within any defense agency.

Outline of this Dissertation

With the problem just defined, Chapter 2 puts the problem in context by describing the status of the Air Force's logistics system in general and more specifically the spares support process (the design of the supply chain). To better understand the concept of system dynamic modeling and how it can support management decisions like choosing the proper PSM levers, Chapter 3 provides a review of exploratory modeling. Chapter 4 discusses the model developed by this dissertation, to include the choice of policy levers, measures of improvement, and how well the model represents the PSM process in general, rather than just the support of the F100 engine. After analyzing the effect of altering each individual parameter in Chapter 5, the specific findings regarding critical parameters, assumptions, and policy configurations is covered in Chapter 6, along with a review of the validity of the model with respect to it's ability to produce results that are consistent with economic theory and real world results in both the F100 demonstration and commercial industry. The dissertation concludes with specific recommendations regarding prospective policy changes and areas for future research to better quantify the affect of PSM levers.

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[26] The "Small Business Reauthorization Act of 2000," Public Law 106-554 passed December 14, 2001 updated many of the small business regulations and extended several programs designed to support small businesses. Online at: http://www.navysbir.com/106-554-SBIR.pdf. (as of January 24, 2003).

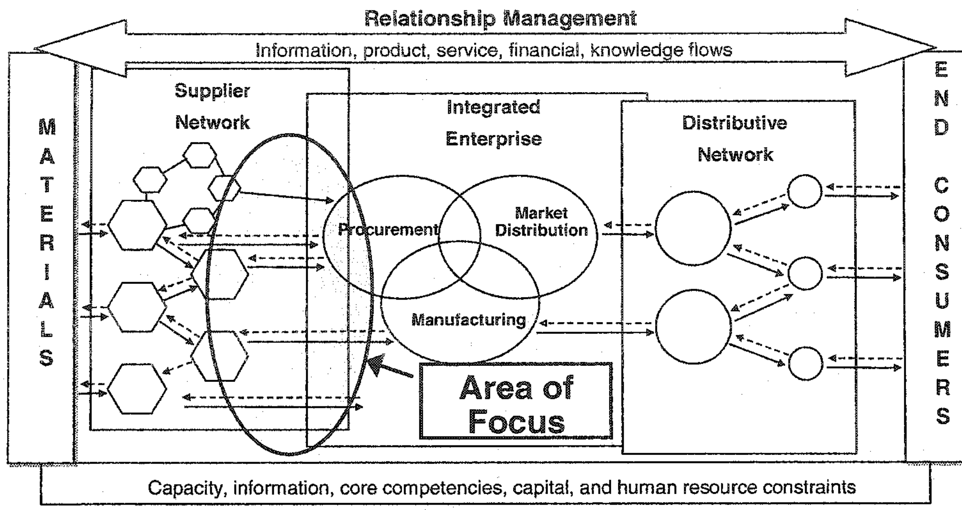
2. Current Support System

While the focus of this research is the management of the PSM process, an understanding of the overall support system in which this process operates is needed. This chapter provides a description of how the current support process is structured to provide parts where and when they are needed, and why the systems that worked in the past are not capable of supporting today's force structure and operational design. After describing the current environment, the chapter concludes with a discussion of change efforts to date, particularly with respect to their inability to produce the coordinated system wide perspective that a system dynamic model provides.

Structure of the Support System

The support system is simply the design and operation of the supply chain that transforms raw materials through intermediaries such as suppliers, companies, and distributors to products for the end customer (see Figure 3). While the composition of this supply chain can vary with respect to the number of companies (or nodes) and the complexity of the links, the need to pass goods and services between companies is present in all but the most vertically integrated supply chains.

Figure 3: Generalized Supply Chain Model*



*Adapted from Bowersox, Donald J., David J. Closs and M. Bixby Cooper, Supply Chain: Logistics Management, Boston, Mass.: McGraw Hill, 2002, p. 6.

Overall, the supply chain (or logistics system) has two main types of components: the companies that transform inputs into outputs, and the links that connect companies. The overall supply chain joins these components into a network in which goods flowing to the end consumer pass through three distinct phases: the supplier network, the integrated enterprise, and the distributive network.

Supplier Network: Most modern goods such as aircraft (or aircraft parts) are far too complex for a single company to produce. Instead, individual components of the end product are purchased from a multitude of suppliers. The number of suppliers needed and the nature of the relationship between these suppliers vary by industry, product, and manufacturer. For a supply chain to perform effectively, this network must be robust to changes in requirements as well as efficient in its operation. While the number of enterprises present in this network and their capabilities are largely predetermined, how an enterprise interacts with this network can vary. For example, an enterprise decides how many suppliers to interact with, as well as the form (contract type) of this interaction. It is this interaction between the enterprise and the supplier network that is the focus of this research effort. For an enterprise to succeed in today's complex business environment it must ensure that this interface is properly structured.

Integrated Enterprise: The heart of any supply chain is the individual enterprise or company that is trying to produce a good or service. This company must determine not only which goods to produce internally and which to purchase from suppliers, but how to organize to efficiently produce goods needed by the end consumer. This paper considers the entire Air Force depot operations as the integrated enterprise. The alignment of work within the various defense agencies, such as the division of work between the Air Force Logistics Centers (ALCs) and the Defense Logistics Agency (DLA) is taken as given and not explicitly captured. This dissertation assumes that the depot functions as a single (albeit large and complex) entity.

Distributive Network: Once an enterprise produces a good or service, a down stream (i.e. distribution) network transmits it to the end customer. For consumer goods this distribution network may take the form of a network of wholesale distributors and individual retail outlets, while specialized industrial goods may be shipped directly from the enterprise to the end customer. Consideration of changes in the distribution system is beyond the scope of this dissertation.

For the overall system to operate efficiently, the individual enterprises within this supply chain must be properly organized, and the links joining them must be designed in such a manner so as not to impede the flow of goods and services throughout the system. With respect to the operation of an individual enterprise, fields such as industrial engineering have attempted to quantify and optimize the physical flow of materials, while various incentive theories and organizational designs have been proposed and tested to ensure the enterprise operates in the most productive possible manner. Additionally, the design of efficient transportation or distribution networks has also been extensively studied.[27] The portion of this supply chain that warrants further attention, and which is the focus of this research effort, is the proper design of the upstream links between the enterprise and its suppliers. Traditional economic models have focused on the interaction between individual enterprises, but lack the ability to capture the complex interaction of this network, as suggested above in Figure 3.

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[27] Within RAND, the Velocity Management program has worked to improve the transportation and distribution of goods for the U.S. Army (See: Dumond, John, et al., *Velocity Management: The Business Paradigm that Has Transformed U.S. Army Logistics,* Santa Monica, Calif.: RAND, MR-1108, 2001). In general the optimal design of a transportation system is one of the basic tasks in the field of Operations Research. For an introduction into the basic solution methodology used to solve a simple transportation problem see Hillier, Frederick S. and Gerald J. Lieberman, *Introduction to Operations Research,* Seventh Edition, Boston, MA: McGraw Hill, 2001, Chapter 8.

Air Force Supply Chain

The Department of Defense defines the supply chain as, "The linked activities associated with providing materiel from a raw materiel stage to an end user as a finished product."[28] A typical supply chain for a repair part centers around the Air Logistics Center or Depot assigned responsibility for that part, but this is not the only organization within the Air Force that has an interest in the performance of the weapon system.

The purchase and long-term support of weapon systems is the responsibility of Air Force Material Command (AFMC). However, their operation and daily maintenance is the responsibility of the operating commands tasked with employing the weapon systems on a daily basis. Within AFMC, the initial design, modification, and procurement of a system is the responsibility of the System Program Office (SPO), while responsibility for the long-term supply and management of repair and replacement parts rests primarily with the individual item managers located at the Air Logistics Centers (ALCs) otherwise known as depots. Finally, there exists a division in the source of supply for a particular part depending upon whether or not it is repairable. The Defense Logistics Agency (DLA) centrally manages most consumable parts, which cannot be repaired, for the entire Department of Defense while repairable parts are managed by the various Air Logistics Centers depending upon the type of part and the nature of the repair. This highly segregated system is led by a variety of organizations and performance is tracked not by the ability to support a particular mission but by various independent short-term metrics. This lack of integration by the components of the supply chain (across both functions and organizations) increases costs and significantly degrades the overall performance of the supply chain.[29]

Currently most parts or National Stock Numbers (NSNs) are managed independently by an item manager and purchased via a locally designed contract at each Air Logistics Center.[30] For example, all parts unique to the C-17 weapon system are managed by Warner Robins Air Logistics Center at Robins Air Force

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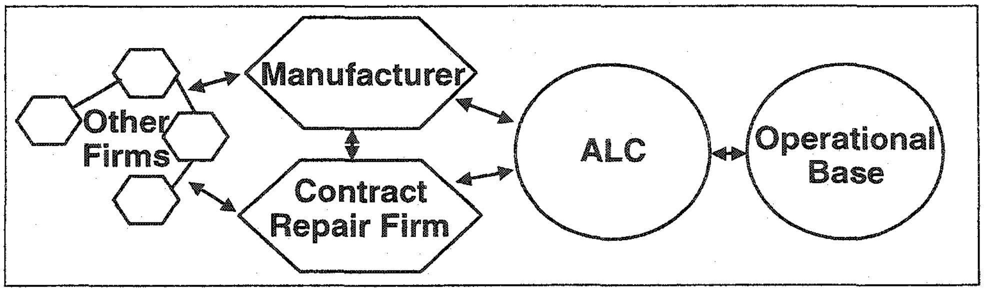
[28] U.S. Department of Defense, *Department of Defense Dictionary of Military and Associated Terms*, Joint Publication 1-02 as amended through August 14, 2002, p. 425.

[29] For a more detailed discussion of how separating the individual parts of a supply chain degrades it's performance see: Lee, Hau L., V. Padmanabhan, and Seungjin Whang, "The Bullwhip Effect in Supply Chains," *Sloan Management Review*, Spring 1997, pp. 93-102.

[30] The DoD assigns a unique National Stock Number or NSN to each unique item it manages. This number identifies both the type of part (i.e. bolt vs. electronic component) as well as providing a unique number to each type of part. NSNs are assigned not to individual items, like serial numbers, but are similar to model numbers identifying different versions of similar items.

Base (AFB), Georgia while parts unique to the B-52 are handled by the Oklahoma City Air Logistics Center at Tinker AFB, Oklahoma. The nature and length of the contract used to source a particular part depends on the type of part, preferences of the local organization, and the currently prescribed method of procurement recommended by headquarters. It is the depot's responsibility to determine the optimal procedures not only for maintaining a part internally, but also for defining all aspects of how the part is handled -- from establishing ordering policies, determining inventory levels and the location of the inventory, to defining the requirements for outside support by manufacturers and commercial repair facilities. Traditionally, when the Air Logistics Centers are determining how to structure the supply chain for a particular part, this invisible chain has been broken into distinct, separately managed links (Figure 4). How suppliers convert raw materials into spare parts is not of interest to the ALC, nor are the activities of the organization using the parts.

Figure 4: Notional Air Force Supply Chain



However, modern supply chain management recognizes the need to seamlessly coordinate the activities of these links into an organized support process. Based on the commercial Supply Chain Operations Reference Model (SCOR),[31] the DoD has developed a plan to link four phases of the supply chain together (source, make, plan, deliver) (Figure 5).[32] Leading this effort for the DoD, the Supply Chain Integration Office's mission is: "To lead the implementation of a modern, integrated materiel supply chain process that fully supports military operational requirements. To promote customer confidence in the logistics process by building a responsive, cost-effective capacity to provide

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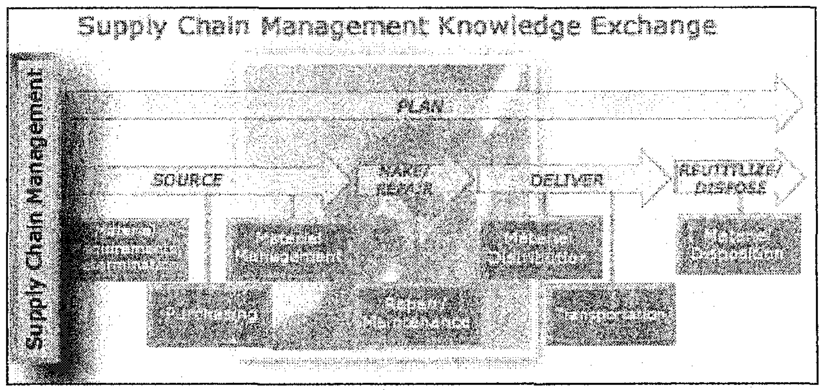
[31] For additional information on the SCOR model see the Supply Chain Council, homepage, November 8, 2002. Online at www.supply-chain.org (as of November 12, 2002).

[32] U.S. Assistant Deputy Undersecretary of Defense (Supply Chain Integration), homepage, October 1, 2002. Online at http://www.acq.osd.mil/log/logistics_materiel_readiness/organizations/sci/html/knowlege_exchange/site/home.htm (as of July 24, 2003).

required products and services."[33] To fulfill this mission a variety of agencies within the DoD are working to modernize the DoD's logistics functions and update how the supply chain operates.

Figure 5: DoD Supply Chain Structure



Source: U.S. Assistant Deputy Undersecretary of Defense (Supply Chain Integration)

Figure 5 shows two important aspects of the DoD's vision of a supply chain. First, the individual functions are aligned with a particular aspect of the process. For example, Material Requirements Determination is seen as part of the sourcing effort, but its impact on the choice of transportation modes is not clear. However, these two activities are highly integrated since parts with low cost and high demand require large inventory levels that can be distributed to a variety of locations while those high cost and low demand items will have only a few items in the overall inventory are often centrally housed and shipped via priority methods when needed. The linear nature of this model prevents clear visualizations and understanding of these interactions. Second, this process does not clearly describe the overall interaction of the various stages of the supply chain. The interaction with the supplier network and the enterprise is hidden within the "source" aspect of the SCOR model, as is the relationship of this model to the end customer. Overall, this model lacks a clear representation of the detailed interactions across the entire supply chain, from raw materials to end customer. It is now recognized both within the commercial business world and the Department of Defense that an overarching end-to-end supply chain vision is needed, and that all phases of the supply chain must be integrated to meet the needs of the end customer in the most efficient manner. The DoD and the Air Force have begun to transform their supply chain, but at this time the final vision of the desired future state and the steps needed to achieve that vision

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[33] Ibid.

are not clear. Nor is there currently a robust model that aids in representing the vision or in aiding the policy decisions necessary to implement that vision.

Description of the PSM Problem

While the previous section has identified a lack of an in-depth understanding of how the PSM process operates, such an understanding is not needed if the current system performs adequately. However, as this section indicates the performance of the current system must be improved to support Air Force systems now and into the future.

To achieve its objective of defending the United States, the Air Force acquires and operates a variety of highly complex weapon systems. A majority of these weapons systems are aircraft that require a significant amount of maintenance to continually operate, to include manpower to perform maintenance tasks as well as a reliable source of spare parts[34]. This research focuses on the method of securing spare aircraft engine parts.

Lack of parts

The General Accounting Office (GAO) has issued several reports during the 1990s documenting the difficulties the Department of Defense has had in procuring and managing spare parts.[35] The current PSM system spends billions of dollars but delivers only minimal levels of support.[36] For example, in recent

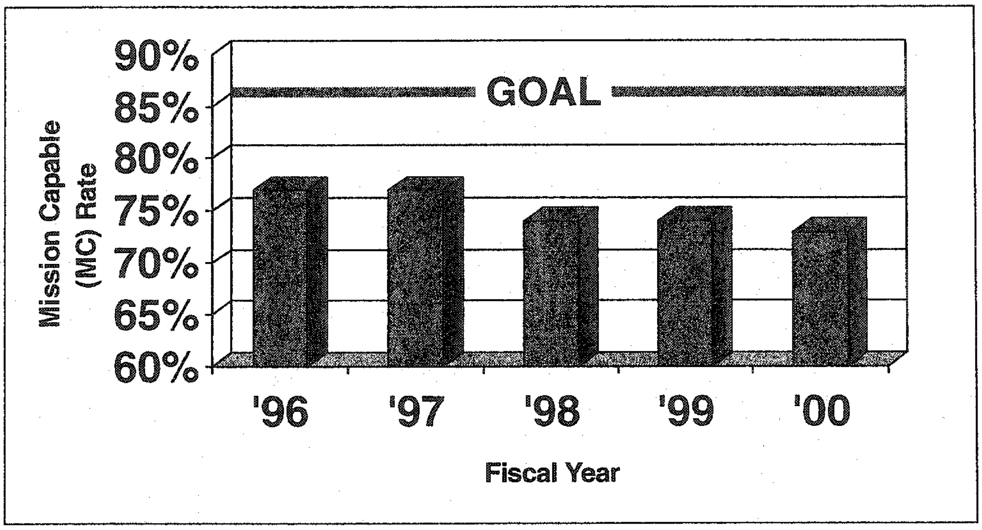
[34] For example, excluding fuel and personnel, flying an F-15 costs about $8,500/hour, compared to $8,900/hour for a C-5, and $13,800/hour for a B-1 in Fiscal Year 2002 dollars. (U.S. Department of the Air Force, *Air Force Instruction 65-503: Cost and Planning Factors*, September 2001. Online at www.saffm.hq.af.mil/FMC/afi65503.html.)

[35] U.S. General Accounting Office (GAO), *High Risk Series: An Update*, GAO-01-263, January 2001, p. 10. This update to the executive and legislative branches discusses the status of high risk areas to include Inventory Management (identified in 1990), Contract Management (identified in 1992), Financial Management (identified in 1995), and Infrastructure Management (identified in 1997).

[36] The Air Force has been fully funded for spare parts since Fiscal Year 1999 with a budget of $3 billion in Fiscal Year 2001. (Rolfsen, Bruce, "Wrench Warfare: Manning and Parts Shortages are Costly Issues for Air Force Maintainers," *Air Force Times*, November 26, 2001.) Overall spending levels for all purchased services, supplies and equipment in Fiscal Year 2002 totals $14.1 billion ($10.1 billion on purchased services and another $4.0 billion on supplies and equipment). (Assistant Secretary of the Air Force (Financial Management and Comptroller), *United States Air Force Statistical Digest FY 2001*, Washington, D.C., 2002, p. 28. Online at http://www.saffm.hq.af.mil/FMC/statdigest/2001/milonly/statdig01.pdf (as of April 21, 2003). For more information on the difficulties in identifying exactly what the Air Force spends on spare parts see, U.S. General Accounting Office (GAO), *Information on the Use of Spare Parts Funding is Lacking*, Report to the Chairmen, Committee on Appropriations, and the Subcommittee on Defense, Committee on Appropriations, House of Representatives, GAO-01-472, June 2001).

years the inability to provide spare parts has directly affected operations and maintenance effectiveness, as evidenced by climbing aircraft Not Mission Capable Supply (NMCS) rates.[37] The GAO reports that Air Force mission capable rates have declined from 79% in 1996 to 73% in 2000, with over half of this decrease attributable to supply problems (See Figure 6). In other words, on average 14% of all aircraft, or about 1 in every seven, are not available due supply problems.[38]

Figure 6: Air Force Aircraft Availability Rates



Source: General Accounting Officer Report GAO-01-587: Parts Shortages are Impacting Operations and Maintenance Effectiveness, June 2001

Compounding the lack of spare parts problem is the growing average age of Air Force aircraft from 17.9 years old in Fiscal Year 1996 to an average of 21.9 years in Fiscal Year 2001.[39] These older aircraft not only require more maintenance per flying hour, hence more parts, but also may contain parts built with obsolete technology, which can be difficult to source.

However, an overall lack of materiel is not the root cause of the supply problems. As of September 30, 1999, the Department of Defense had over $1.6B

[37] Workman, Jim, "Aviation Spare Part Inventory - Funding for Readiness," briefing delivered by Office of the Director, Program Analysis and Evaluation (OSD/PA&E) at the Annual Department of Defense Cost Analysis Symposium, Williamsburg, VA, February 1, 2001.

[38] U.S. General Accounting Office (GAO), *Parts Shortages are Impacting Operations and Maintenance Effectiveness*, Report to Congressional Committees, GAO-01-587, June 2001, p 4.

[39] Assistant Secretary of the Air Force (Financial Management and Comptroller), *United States Air Force Statistical Digest FY 2001*, Washington, D.C., 2002, p. 107. Online at http://www.saffm.hq.af.mil/FMC/statdigest/2001/milonly/statdig01.pdf (as of April 21, 2003).

in spare parts inventory on order that was not needed based on current requirements.[40] It is not known what percentage this inventory is for Air Force weapons systems. Based upon the amount of money the Air Force spends upon spare parts, lack of funding in itself is not the source of the problem. In 1999, the Air Force received $904 million in supplemental funding to support operations in Kosovo ($397 million), and to buy engines and spare parts to improve operational effectiveness.[41] Since 2000, the Air Force has fully funded the spares accounts spending $2.6B for aircraft parts in 2000. This amount has increased to $3.0B in 2001 and to $3.8B in 2002. However, additional funding to purchase parts has not solved the Air Force's problem of ensuring that the right mix of parts is purchased and available when needed.

Within today's budget constraints it is highly unlikely that the Air Force can increase expenditures enough to overcome the inefficiencies of the system. Overall, defense spending has remained relatively constant in the past decade, but it is becoming a smaller percentage of total federal spending (Figure 7).[42] To meet the challenges ahead, the scarce resources devoted to defense programs must not be spent on inefficient and ineffective support programs, but used to update and modernize our defense capabilities. As noted by the National Defense Panel, unless the acquisition and support areas are transformed there will be insufficient funding to complete required modernization programs without reducing the operational capability or size of the defense department.[43]

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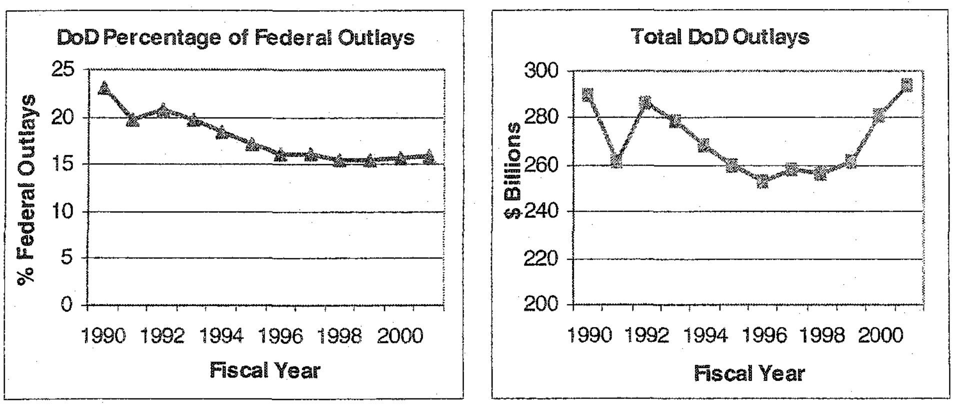
[40] U.S. General Accounting Office (GAO), *Information on the Use of Spare Parts Funding is Lacking*, Report to the Chairmen, Committee on Appropriations, and the Subcommittee on Defense, Committee on Appropriations, House of Representatives, GAO-01-472, June 2001, p 4.

[41] U.S. General Accounting Office (GAO), *Parts Shortages are Impacting Operations and Maintenance Effectiveness*, Report to Congressional Committees, GAO-01-587, June 2001 p. 5.

[42] U.S. Government Printing Office, *Budget of the United States Government Fiscal Year 2003: Historical Tables*, Washington, D.C., 2002.

[43] National Defense Panel, *Transforming Defense: National Security in the 21st Century*, Arlington, VA, December 1997.

Figure 7: DoD Spending by Fiscal Year



Source: Budget of the United States Government Fiscal Year 2003: Historical Tables

Different Support Environment

While the ability to deliver the right parts at an affordable price is a major problem, it is not clear exactly how to do it. Existing Air Force processes were designed to operate in a Cold War environment where costs and efficiency were secondary concerns to those of ensuring maximum effectiveness of the forces in defending the United States against a massive invasion. This massive invasion scenario no longer exists. Additionally, there has been a transformation in the types of missions that military forces must perform in the 21st century. Gone are the large traditional force-on-force conflicts in which the winner is the side with the largest military power and the biggest logistical pipeline. Today's conflicts arise much more quickly and are smaller in scale but less predictable in their location, nature, and duration. To meet these challenges in the modern era the Air Force requires less, but much more sophisticated equipment, and a responsive, flexible, and robust support network. Included in the current military doctrine is the need to provide the joint force Focused Logistics defined as providing the right supplies at the right place, time, and quantity for a range of military operations.[44] What is not clear is how to achieve this concept.

[44] Joint Vision 2020 states that to achieve the current operational concepts of dominant maneuver and precision engagement, the use of Focused Logistics is required. U.S. Joint Chiefs of Staff, *Focused Logistics: A Joint Logistics Roadmap*, Washington, Joint Chiefs of Staff, 1997. Online at www.acq.osd.mil/log/logistics_materiel_readiness/organizations/lmr/assetts/programs/focuslog.pdf) (as of November 8, 2002). U.S. Joint Chiefs of Staff, *Joint Vision 2020*, Washington, Joint Chiefs of Staff, 1999, p. 24.

Lots of change but no oversight

One major concern with the current logistics transformation and other DoD improvement initiatives is the often-narrow focus and lack of coordination among the initiatives, resulting in actions that are not always consistent with the overall plan.[45] For example, initiatives to work more closely with suppliers fail when contract lengths are not long enough for the relationship to show meaningful improvements. Without a big-picture focus, individual reform efforts may work to achieve conflicting results and will fail to achieve their goals because synergies and inter-relationships between the reform efforts are not taken into account. Significant reform often requires a corporate focus rather than optimizing each individual organization or step in a process.[46] Well-meaning incentives at the individual level may actually lead to counter productive behavior.[47] As noted by the GAO, the DoD has over 400 ongoing individual initiatives to improve logistical support, but has no overarching plan to integrate them.[48] Without an overall understanding of the interaction of the various changes, lack of coordination is likely to continue, and despite the implementation of multiple improvement strategies, overall system performance may not significantly improve.

As with the military community, modern commercial practices of PSM have evolved over the past decade and now include new procedures, organizational structures, and operating concepts that have drastically improved performance while reducing costs. Examples include reducing the supply base and forming closer relationships with key suppliers to improve performance and reduce costs.[49] However, many of these practices lack empirical validation as to their ability to effect change outside a particular business environment. Additionally, although the DoD has historically implemented changes to individual policy levers in isolation, the interaction of these various change efforts is also not well documented. As noted by Marcus, without accounting for

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[45] U.S. General Accounting Office (GAO), *Strategic Planning Weaknesses Leave Economy, Efficiency, and Effectiveness of Future Support Systems at Risk*, Report to Congressional Committees, GAO-02-106, October 2001.

[46] Shapiro, Benson P., V. Kasturi Rangan, and John J. Sviokla, "Staple Yourself to an Order," *Harvard Business Review*, July-August 1992, pp. 113-122.

[47] Elliff, Scott A., "Organizing for Excellence: Five Case Studies," *Supply Chain Management Review*, Winter 1998, pp. 38-45.

[48] U.S. General Accounting Office (GAO), *Major Management Challenges and Program Risks*, GAO-01-244, January 2001.

[49] A detailed discussion of the policy levers included in this dissertation is provided in Chapter 4. The specific effects of altering those levers on the PSM process are documented in detail in Appendix C.

these interactions any efforts to change are likely to fail.[50] Corporate experience indicates that 40-90% of organizational change efforts fail during implementation.[51] Failure can be caused by technical failure (change didn't follow correct change management techniques) or social failure (good technical implementation, but the idea lacked organizational commitment or mis-specified a cause and effect relationship).

What is needed is an integrated framework from which to measure and observe the interactions between various change levers and a method to determine the best direction for future improvement initiatives. Within the arena of PSM, this research attempts to fill that void and provide such a model. In the next section, modeling in general and system dynamic modeling with exploratory analysis in particular is described as it can be used to help with the PSM problem. Chapter 4 then provides a high-level description of the model, with additional details found in Appendix A.

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50 Markus, M. Lynne, "Lessons from the field of organizational change," *Journal of Strategic Performance Management*, April/May 1998, pp. 36-45.

51 Ibid.

3. Modeling for Policy Improvement

This chapter discusses the use of modeling and simulation to support policy decisions and how exploratory analysis and system dynamic modeling can help identify the effect of various policy alternatives. Also included is some discussion regarding the choice of software and the sources of data used to support model development, execution, and evaluation. The chapter concludes by describing how to ensure the results of the model are applicable and relevant to the decision of how to select the proper configuration of the PSM policy levers to support the F100 jet engine within the Air Force.

A model is a simplification of reality, which attempts to capture critical aspects of a system or process, while removing details thought to be omitable or extraneous to the objectives of the decision. Decision makers develop and use models of situations to assist in clarifying the critical aspects of pending decisions. These models can be internal mental pictures of how systems operate or explicit external models developed by one or more individuals. Research shows that the presence of even a simple model and some historical case studies can significantly improve the performance of decision makers. In particular, Hoch and Schkade find that providing decision makers with a simple linear model and a database of historical examples helps with the decision of forecasting the results of an unpredictable business environment.[52]

Interestingly, most people have difficulty incorporating more than five or six parameters into an accurate mental model.[53] Conversely, by developing a mathematical or computer model of the decision rather than relying on their own internal mental model, policy makers can reduce the common mistakes of excessive simplicity, latency, and lack of feedback. Latency refers to the tendency of individuals to place increased emphasis on the last observation and discounting events that occurred further in the past. For example, when flipping a coin and a head appears twice in a row, people often believe a head is more likely (on a streak) on the next flip regardless of the fact that a coin toss is truly a random event. An individual's mental model is also often based upon simple

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[52] Hoch, Stephen J. and David A. Schkade, "A Psychological Approach to Decision Support Systems," *Management Science*, Volume 42, Issue 1, January 1996, pp. 51-64.

[53] Forrester, Jay W., "Policies, Decisions, and Information Sources for Modeling," in Morecroft, John D. W. and John D. Sterman, eds., *Modeling for Learning Organizations*, Portland, OR: Productivity Press, 2000 pp. 51-84.

casual relationships devoid of the actual workings of the underlying process including feedback loops present in the real world.[54] For example, a sales representative may feel that giving discounts is a good business strategy for increasing sales. However, he/she may fail to notice that by increasing the volume of sales, the production capacity of the company is exceeded, thereby delaying the delivery of all orders.

The above discussion is not meant to imply that mental models are not an important source of information. In fact, one of the critical features of a good decision support model is the ability to capture information that is contained in experts' "mental database" as well as in traditional numerical databases.[55] Capturing both allows a model to better represent the functioning of a real world system, to include many of the complex interactions between various parameters.

Historical Uses of Models

Modeling is not a new activity. Models and simulations have been frequently used to represent real world events and aid decision makers. Physical models such a building miniatures, or wind tunnel aircraft and analog models such as maps and charts, have been used for centuries and provide easily understood representations of larger phenomenon. Mathematical models, while more abstract, are also not a new concept. Economist Alfred Marshall published the basic model of supply and demand to determine the price of a good in 1890.[56] The dawn of the computer age enabled mathematical models to become much larger, represent more complex relationships, and to include more input parameters. However, with this increase in size, mathematical models became more difficult to design and operate. Even today, when carefully analyzing the interaction of a few key parameters, mathematical models remain limited in their scope and applicability. For example, economic models such as the Ward-Tan quality model used by Hosek and Mattock (2002) are useful in describing how a particular attribute such as personnel quality is impacted by various policy decisions. However, they lack the scope needed to incorporate additional non-

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[54] Sterman, John D., *Business Dynamics Systems Thinking and Modeling for a Complex World*, Boston, Mass: McGraw-Hill, 2000, p.28.

[55] Forrester, Jay W., "Policies, Decisions, and Information Sources for Modeling," in Morecroft, John D. W. and John D. Sterman, eds., *Modeling for Learning Organizations*, Portland, OR: Productivity Press, 2000, p. 72.

56 Marshall, Alfred, *Principles of Economics*, Macmillan and Co., Ltd., 1920. Online at www.econlib.org/library/Marshall/marP0.html (as of May 6, 2003).

quality measures that might be of interest.[57] Dewer, Bankes, and Edwards (2001) also rely on a parametric model of the U.S. Army's expandability, but they too recognize the need for a more robust exploratory analysis of the results of the model, to include comprehensive graphic displays of alternative sets of the model's input parameters.[58]

In the realm of PSM, mathematical models have been used to represent various portions of the process, to include predicting demands,[59] designing transportation or inventory systems networks;[60] or to represent the overall process of how parts flow through the system. Other models apply economic theory to the behavior of individuals and enterprises in a variety of business settings. For example, RAND developed a simulation model to determine the best contract structure to purchase spare parts.[61] While these models are helpful in understanding a particular problem or relationship, they are limited in their ability to represent the complex synergies or inter-relationships among parameters that change over time. Finally, while the limited focus of such models allows them to precisely represent the significant characteristics of a single relationship, they lack the broader scope needed to represent and aid in larger, more complex policy decisions.

These limitation suggests advantages of larger, more complex models, but there are disadvantages associated with such models as well. The use of larger, more complex models is not always an improvement. In many cases this has occurred, with organizations developing large-scale, complex statistical models, which attempt to recreate almost every detail of their process. Davis and Bigelow suggest that a simpler, low resolution model capturing the key attributes of the policy problem at hand is often preferred when supporting policy decisions or conducting exploratory analysis.[62] They argue that unlike large scale statistically based models, the quality of an exploratory model should be judged not on it's ability to document each individual detail of the process,

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[57] Hosek, James R. and Michael G. Mattock, *Learning about Quality: How the Quality of Military Personnel is Revealed Over Time*, Santa Monica, Calif.: RAND, MR-1593-OSD, 2002.

[58] Dewar, James A., Steven C. Bankes, and Sean Edwards, *Expandability of the 21st Century Army*, Santa Monica, Calif.: RAND, MR-1190-A, 2001.

[59] Headquarters U.S. Air Force (Installations and Logistics), "Logistics Transformation Demand Planning Pathfinder Final Report," Briefing, November 2001.

[60] Hillier, Frederick S. and Gerald J. Lieberman, "Introduction to Operations Research," Seventh Edition, McGraw Hill: Boston, Mass., 2001.

[61] Keating, Edward G., *Government Contracting Options: A Model and Application*, Santa Monica, Calif.: RAND, MR-693-AF, 1996.

[62] Davis, Paul K. and James H. Bigelow, *Motivated Metamodels: Synthesis of Cause-Effect Reasoning and Statistical Metamodeling*, Santa Monica, Calif.: RAND, MR-1570, 2003, p. v.

but the ability to capture the interaction of the various policy levers in a manner that provides insight into the question at hand. As Davis and Bigelow recommend, the type of model developed in this dissertation strives to shed light on the interactions of various PSM levers without becoming entangled in the details of each individual purchase.

Exploratory analysis, by taking a somewhat less precise quantitative approach, recognizes the need to include parameters that are more subjective in nature, such as the quality of a contract or relationship between two enterprises, which is difficult to define quantitatively. Analysts can use exploratory analysis to develop a broader framework of how policy decisions affects measures of interest. However, more subjective qualitative models, result in an analysis that is difficult to replicate and often lack the ability to easily determine the effects of changes to a particular assumption or input parameter. A good example of an analysis of this type, using various strategy drivers as metrics in a non-quantitative manner, is McGinn et al.'s Strategy Development Framework, which provides policy makers with a method of making decisions regarding an optimal strategy.[63]

Overall, the challenge for quantitative analysis is achieving a balance between a rigorous quantitative approach, and the need to incorporate relevant aspects of the problem under consideration including qualitative, subjective ones. As noted by John D. W. Morecroft, "the real key to effective strategy support is not simply having a model, but using it in a structured dialog with executives."[64] Therefore, the "optimal" policy model must not only be quantitatively based upon the operation of real world systems to suggest the outcome of various policy decisions, but must also incorporate relevant qualitative aspects of the problem in a structure that encourages and facilitates discussion. The technique of exploratory analysis is one method of balancing this need for quantitative rigor while including sufficient variation in qualitative parameters not known with certainty. Thus, one criteria for the model developed in this dissertation is that it must be capable of producing results that suggest specific policy recommendations regarding the anticipated effect of altering this configuration. These results are then used to support the recommendation of one or more policy changes.

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[63] McGinn, John G., et al., *A Framework for Strategy Development*, Santa Monica, Calif.: RAND, MR-1392-OSD, 2002.

[64] Morecroft, John D. W., "Strategy Support Models," *Strategic Management Journal*, Vol. 5, Issue 3, July-September 1984, pp. 215-229.

Exploratory Analysis[65]

Exploratory analysis can be defined as the process of determining the performance of a model or system over a broad range of input parameters. Unlike many traditional analytic techniques, which seek to find the "optimal" solution to a particular problem, exploratory analysis recognizes that given the uncertainty surrounding most policy problems, a solution that is robust to variations in key parameters can be preferable to a "best" solution that is highly dependant on a particular parameter value. Rather than offering one solution, this analytical process explores a variety of alternative settings (or combinations of settings) for both policy levers and parameters of the model that may not be known with certainty – thus finding a solution that performs well in a multitude of alternative configurations. Additionally, through the associated large number of computational experiments, this exploration process provides a rich database of policy actions and results that can be used to identify critical interrelationships, suggesting where additional research might improve the overall accuracy and performance of the model.

One approach to exploratory analysis begins with the development of a relatively "simple" model of the process under consideration. The model must be simple, not in terms of its design, but in its ability to quickly execute multiple iterations when performing large computational experiments. Like all experiments, the design of this analysis allows the manipulation of variables and the observation of their effect.[66] While not attempting to capture all aspects of the system in question with exact precision, the model must be able to capture critical drivers and relationships with known or estimated parameters. This "simple" model is judged by the ability to mirror the real world relationships between policy levers and measures of interest, rather than its ability to capture every detail.

In order to explore the range of potential outcomes in the presence of a great degree of uncertainty, multiple iterations are required. However, unlike traditional sensitivity analysis that explores small changes around a single model output, exploratory analysis examines the variation of multiple policy levers and model parameters simultaneously to gain an understanding of how system

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[65] The contents of this section are loosely based on the ideas of Steven Bankes in, Bankes, Steven, "Exploratory Modeling for Policy Analysis," *Operations Research*, Vol. 41, Issue 3, May-June 1993, pp. 435-449.

[66] By referencing potential policy changes to a "base case", this analysis uses a control group to understand the degree and direction of change in various outcome measures. For a more detailed discussion of experimental designs and their use in supporting policy decisions see: Cooper Donald R. and C. William Emory, *Business Research Methods*, Chicago, Il.: Richard C. Irwin, Inc., 1995.

components interact. This exploration process can result in additional modifications to the model to expand the potential input space, or to consider combinations of input parameters not normally included in a traditional analysis. The overall goal is to create a landscape of how the inputs potentially affect output measures as well as the assumptions required to support these results.

Exploratory analysis does not focus on the individual details of a process, but rather, it attempts to gain an understanding of how the pieces of the process interact. Accordingly, the results of a particular run of the model are not of primary interest, but instead how the results change between runs as the parameters of the model are changed. By maintaining this big picture focus, general observations regarding the nature of the system can be made with less potential for introducing systematic biases.[67] In other words, this type of analysis attempts to look from the outside at the system as a whole, rather than independently considering each individual transaction.

In general, the results of this type of exploration are three fold. First, the analyst can determine if the model appears to capture all of the important interactions within the real world process. Unanticipated results can be analyzed in more detail to determine if the model has identified something non-intuitive, or if the model has failed to capture some critical aspect of the process that has caused the unexpected results. In this manner, the analysis helps identify previously unknown relationships that must be analyzed and incorporated into the model or accounted for when developing recommended policy changes. The second, and more interesting result from a policy perspective is the ability to identify combinations of the input levers that result in favorable results, despite uncertainties in both the design of the model and in real world operations. Finally, as with traditional prescriptive models, exploratory models can conduct "what if" exercises to consider changes to future operating procedures and environments. By designing exploratory models to conduct a vast number of iterations, additional runs for new "what if" drills come at little extra cost.

Use of System Dynamics

Conducting an exploratory analysis based on a large number of computational experiments requires rapidly running a set of calculations and

[67] For example if three parameters are estimated with 10% accuracy and their errors are correlated (all estimated high or low) and multiplied the resulting value could be as high as 33% overstated ($1.10^3=1.331$). If the product can be estimated directly with the same 10% accuracy, the compounding effect of the errors associated with estimating each parameter individually can be avoided.

hence a relatively "simple" simulation of the process. On the other hand, policy questions such as how to design a PSM process require a simulation that incorporates sufficient detail and the dynamic interactions of various model components. Models using the system dynamic approach are particularly suited to this need. System dynamic models incorporate time as an important factor and can involve the study of how a system reacts to changes that occur only once or that vary with time. Unlike strict econometric models designed to document causal relationships between inputs and outputs, system dynamic models take a more holistic view of a problem and attempt to explain how various components and levers interact over time, particularly where feedback loops occur.

As a particular class of simulation models, system dynamic models are identified by the presence of two key features: The ability to rapidly design a model of the system, execute the model, and analyze model results based on a graphical display; and the use of a timed stepped modeling environment.

1. Graphical Display. Visualization of the system and its processes is important, particularly when modeling processes that are not well understood. The purpose of modeling is to examine the structure, relationships, and functional forms of the process under analysis. Unlike purely mathematical models, system dynamic models use a graphical process to conceptualize, design, and display the structure and relationships of the model, as well as to present model inputs and outputs graphically. In addition to formulating policy recommendations, a pictorial based model helps enlighten policy makers as to the inter-workings of the process to help inform their decisions. In the case of PSM, as previously discussed enlightening policy makers as to the inner-workings of the process is as important as the numerical results. This allows not only the improved design of a given process but gives decision makers the knowledge necessary to make future decisions with this new understanding. An object based modeling software such as most modern system dynamic modeling packages can easily convey to them the structure of the model.

2. Time stepped environment. Dynamic models follow a process through time and capture the significant changes in the state of objects in the model. These state changes can either be discrete event-oriented actions (i.e. every time a customer arrives) or the passage of a particular period of time (i.e. every month). In the PSM process, while the failure of individual parts start the sourcing action, in general in the Air Force policy decisions such as how many parts to order and from who typically occur on a periodic basis. By separating time into discrete intervals (months for this analysis), changes in demands for particular items, contract status, and inventory levels can be easily represented.

Thus, system dynamic model's time stepped processing is needed to represent the dynamics of the PSM process.

These two characteristics make system dynamic models ideally suited for exploratory analysis, which intends not to empirically derive the exact nature of the relationship between a few parameters, but to gain an understanding of how an entire system operates. The benefits of a system dynamic model in helping untangle the complex interaction of the various PSM policy levers is summarized in the following quote from an article on using such models for management education:

> "System dynamics offers a framework for conceptualizing complex business (and other) situations, tools to identify the physical, organizational, and decision-making structure of the systems, and simulation methods to infer correctly the dynamics of these structures."[68]

Software Chosen

While computer simulations can now perform a vast number of calculations, many models rely extensively on symbolic codes with limited visual displays. Historical simulation efforts require the knowledge of computing languages and the development of extensive quantities of computer code.[69,70] These are based either in standard programming language (such a C++) or language developed specifically for simulations (Simscript), but all require a knowledge of the software to interact with the model in any depth.[71] This dependence on software intensive models largely limits their interactions to those few personnel with sufficient computer skills. Modeling results have to be "translated" into charts or other visual formats to easily convey the results to policy makers. Modern simulation software facilitates the graphical

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[68] Graham, Alan K., John D. W. Morecroft, Peter M Senge, and John D. Sterman, "Model-Supported Case Studies for Management Education," in Morecroft, John D. W. and John D. Sterman, eds., *Modeling for Learning Organizations*, Portland, OR: Productivity Press, 2000 pp. 219-241.

[69] Cloud, David J. and Larry B. Rainey, "Introduction to Modeling and Simulation," in Cloud David J. and Larry B. Rainey, eds., *Applied Modeling and Simulation: An Integrated Approach to Development and Operation*, New York: McGraw-Hill, 1998, pp. 1-18.

[70] An example of a linear programming logistics model and the difficulties associated with simplifying such a model so it can be used in a corporate setting can be found in, Klingman, Darwin, John Mote, and Nancy V. Phillips, "A Logistics Planning System at W. R. Grace," *Operations Research*, Volume 36, Issue 6, November- December 1988, pp. 811-822.

[71] Fall, Tom, "Implementing Models and Simulations in Hardware and Software," in Cloud David J. and Larry B. Rainey, eds., *Applied Modeling and Simulation: An Integrated Approach to Development and Operation*, New York: McGraw-Hill, 1998, pp. 331-368.

representation of the process under consideration: with separate visual/metaphorical input and easily manipulated graphical output.

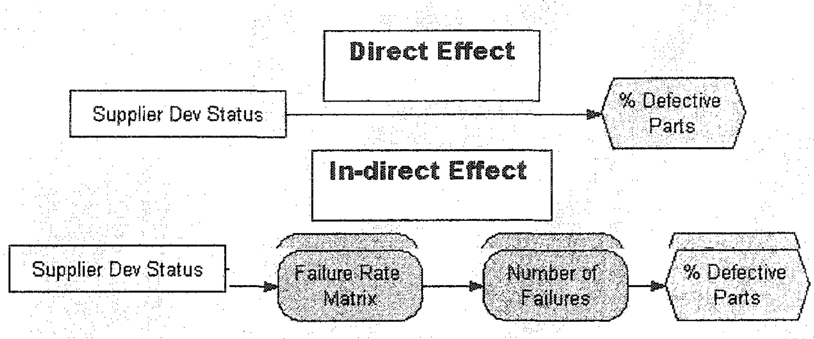
Analytica is a system dynamic modeling software that is particularly well suited to this task through its use of influence diagrams. The use of influence diagrams provides an easily understood method of representing how the various factors in the PSM process interact. Influence diagrams represent the interaction of various components (nodes) through quantitative links (influence arcs). They provide the ability to graphically represent not only the change in physical items, like the monthly inventory of a particular part, but to also capture non-physical changes such as the certification rate of suppliers.

Unlike traditional system dynamic stock and flow models, which only capture the movement of actual physical material, influence diagrams also capture the non-material interaction of policy levers. Nodes in the model represent decision points, variables, system values, input data, or objective values that interact to form the overall system. Connecting these nodes are influence arcs, which express the relationship between the nodes in quantitative terms. These arcs represent evidential relationships between the parameters of the model that may or may not be causal in nature.[72] Influence arcs can be used to represent knowledge and beliefs regarding the effects of a variable's value on other parameters in the model. For example, increasing supplier development efforts can improve the outcome metric of part quality directly, without having to model the details of how increased supplier development alters the probability of failure for each individual part (see Figure 8 for an example of an influence diagram).[73]

[72] Morgan, M. Granger and Max Henrion, *Uncertainty A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge, UK: Cambridge University Press, 1990, p. 262.

[73] For a more detailed discussion regarding the nature of Analytica and how it compares to traditional system-dynamics modeling packages see Chapter 10 in, Morgan, M. Granger and Max Henrion, *Uncertainty A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge, UK: Cambridge University Press, 1990, pp. 257-288.

Figure 8: Influence Diagram Example



Using this relatively simple pictorial format, complex systems can be captured in a structure that not only contains a great deal of specific information, but can be used to provide a concrete reference point when discussing the nature of the PSM process and how the various policy levers interact. The resulting diagrams of the process, lend visibility into the nature of the system being analyzed and provide a range of insights irrespective of the actual quantitative values placed within the model.[74] The use of this type of simulation software enables the modeler to build a multi-layered model, which combines a high level understanding of the system as well as detailed interactions between individual parameters. This allows policy makers to concentrate on the overall structure and design of the system, with functional form of the relationships between model parameters and the actual data explicitly defined later at a more detail level.

This dissertation uses the software Analytica to build a model of the PSM process. Selecting Analytica as the modeling environment is based on three criteria. First, like other modern system dynamic modeling software packages, Analytica has an easy to use graphical format supporting the presentation of the model to non-modeling personnel. Second, Analytica excels in its ability to process multi-dimensional arrays. By describing various policy levers as an array of possible settings (i.e. a reduction in the supply base of 0, 10, 20, 50 or 75 percent), an exploration of how changing the various input measure affects each outcome measure can be easily accomplished. Figure 9 shows an Analytica output screen in which adjustments to the policy levers changes the outcome measure of quality. Finally, while there are other simulation packages that

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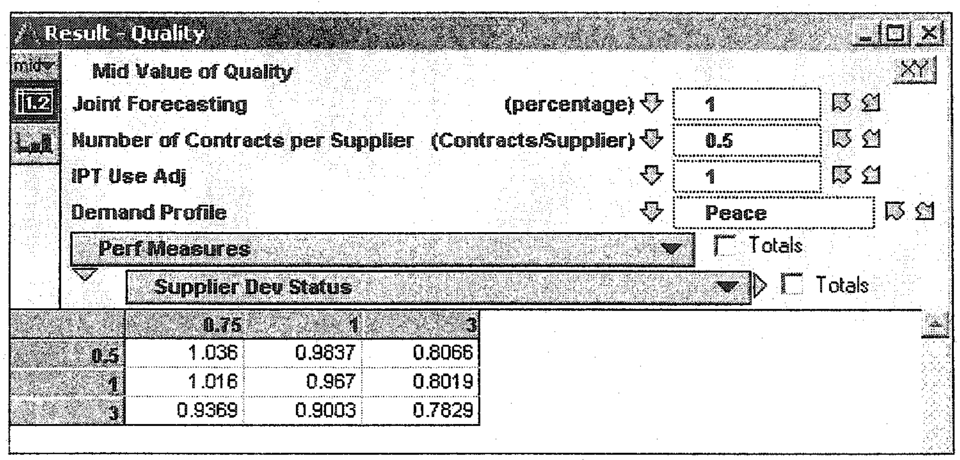
[74] Wolstenholme, Eric F., "A Systematic Approach to Model Creation," in Morecroft, John D. W. and John D. Sterman, eds., *Modeling for Learning Organizations*, Portland, OR: Productivity Press, 2000 pp. 175-194.

support this type of model, Analytica is the one most familiar to the author of this dissertation. Thus, analytical efforts are devoted to the study of the process being modeled rather than learning a new software package.

Figure 9: Sample Outcome Measure



Data Sources

Building and operating a model of a real world process requires three types of data: input data, system and process data, and test data.[75] For this analysis, input data represents the list of parts and their attributes that the PSM process supports. System data is the information needed to build the system dynamic model. Unlike input data, such as the failure rate of a particular part, the structure of this process is not clearly understood. The nature of the interaction of the various model components must be collected from a variety of sources. Finally, after developing the model and analyzing its output, some additional data is needed to ensure that the results of the model sufficiently represent reality and can be used to make policy decisions. The sources will vary for each of these types of data.

Input Data

The primary source of data to populate the Analytica model is parts and performance data from the PSM demonstration of the F100 engine at Tinker AFB

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[75] Bennett, Bart, Richard Hillestad, and Gordon Long, "Producing and Managing Data," in Cloud David J. and Larry B. Rainey, eds., *Applied Modeling and Simulation: An Integrated Approach to Development and Operation*, New York: McGraw-Hill, 1998, pp. 269-330.

(see Appendix B for additional information regarding the specific data used in this model). A separate analysis of each of the parts on the engine was completed to determine spending and suppliers to develop a sourcing strategy for the F100 demonstration. This analysis provides not only a list of parts of the engine but also their demand patterns and acquisition methodology (e.g. type of contract used to source each part). Using data from an actual weapons system, the findings of this dissertation can be used to formulate specific F100 policy recommendations and suggest important areas of investigation in order to determine the applicability of the model under other assumptions.

System and process data

In addition to data on specific engine parts needed to populate the model, building a model of the PSM process requires information about the process itself. Determining the nature and direction of the effects of the various model components required an extensive review of commercial practices and academic economics literature, as well as input from experts from the Air Force, academia, and industry regarding the nature of the relationships with respect to the parts of interest.[76]

An example of how these three data sources (commercial practices, economic literature, and expert opinion) interact to establish the effect of altering the policy levers and the functional form of this relationship is how reducing the number of suppliers changes the price paid for each item. Economic literature suggests that while having fewer suppliers can improve the efficiency of the transaction (lower total transaction costs) the remaining suppliers can use their leverage to increase prices.[77] However, recent commercial practices have found that if buyers can decide who to award their business to, they control the monopoly power and fewer suppliers increases this buyer leverage resulting in lower prices.[78] When modeling the Air Force practices, due to the ability to secure cost and pricing data from sole suppliers, it was determined that only when the number of suppliers is reduced below three do prices increase. For all

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[76] In addition to ongoing dialog with experts in the Air Force, RAND, and commercial industry to learn more about the PSM process, formal interviews were conducted with several experts in purchasing and supply management from Oklahoma ALC in May 2003. A draft of the model was used to structure these interviews and to correct any errors or omissions in the PSM model.

[77] Williamson, Oliver E., *The Economic Institutions of Capitalism*, New York: The Free Press, 1985, p. 25.

[78] Cox, Andrew., Joe Sanderson, and Glyn Watson, "Supply Chains and Power Regimes: Toward an Analytic Framework for Managing Extended Networks of Buyer and Supplier Relationships," *The Journal of Supply Chain Management*, Spring 2001, pp. 28-35.

other reductions, the increased buyer leverage from consolidating all requirements with fewer suppliers results in lower prices. Additional details on this and other links developed in this model can be found in Chapter 4 and Appendix C.

One key feature of the exploratory analysis process is the fact that as the model is developed, those links that are critical to the results (due to their functional form or value) are identified. The validity of those links can be confirmed through further analysis while links that are not critical to the model's results can be based on more speculative data sources. Without this exploratory process, policy makers often overstate the sensitivity of the model to changes of many of its parameters. Thus, only those parameters critical to the results need to be specified with increased precision.[79] For example, in the field of logistics shipping times are considered to be an important aspect of the sourcing process, but the amount of time needed to ship parts from suppliers to the Air Force is not known with certainty. During the exploration of the model, it was found that this delivery time was small and relatively insignificant when compared to the time required to order and produce parts (a few days as compared to months in many cases). Thus, if a more accurate estimate of the time required to source parts from suppliers is desired efforts should not focus on determining delivery times more accurately, but focus on the true drivers of total sourcing time, administrative and production lead times.

Test Data

Testing the model requires additional data regarding the ability of the model to represent reality and to make accurate predictions about new unobserved sets of input parameters. This test data for validation comes primarily from the Air Force F100 demonstration as well as commercial examples of enterprises using the policy levers of PSM. If the model accurately recreates these environments, it will provide confidence that the model results under alternative assumptions are correct. The test data will play a significant role in the verification and validation process discussed next.

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[79] Forrester, Jay W., "Policies, Decisions, and Information Sources for Modeling," in Morecroft, John D. W. and John D. Sterman, eds., *Modeling for Learning Organizations*, Portland, OR: Productivity Press, 2000 p. 68.

Verification and Validation

Ensuring that the results of the model represent something of value that can be used to inform policy decisions requires two interrelated efforts: verification and validation of the model. Verification is the process of ensuring that the model operates as intended while validation refers to testing the model's ability to accurately represent the real world environment for the purposes of the analysis. In other words, was the model built correctly, and does it sufficiently conform to that piece of reality of interest to the decision maker.

Verification

Verification is formally defined as the, "process of determining that the model implementation accurately represents the developer's conceptual description and specifications."[80]

For the object based model developed in this dissertation, verifying that the individual nodes are linked properly is relatively simple. The difficultly is in confirming that the logic within each of the influence arcs has been properly coded. This is accomplished by operating the model with a small set of known sample data, and then comparing the results of each individual aspect of the model to those computed manually. For example, confirming that increases to production lead time correctly affect customer wait times is difficult with a model with over 100 parts. But with a part list of only 5 items, the wait times can be manually computed for each part and time period to confirm that on average, for this reduced data set a 10% increase in production lead times result in a 3% average increase in customer wait time. After verifying the model's performance for this sub-set of parts, it is reasonable to assume that it has been designed correctly and will operate as intended.

Validation

Validation, or ensuring the model sufficiently represents the real world, is a more difficult task. Validity is formally defined as the, "process of determining the degree to which a model is an accurate representation of the real world from the perspective of the model's intended uses."[81] Limiting the perspective of this

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[80] Pace, Dale K., "Verification, Validation, and Accreditation," in Cloud David J. and Larry B. Rainey, eds., *Applied Modeling and Simulation: An Integrated Approach to Development and Operation*, New York: McGraw-Hill, 1998, p. 371.

[81] Ibid, p. 271.

validation effort is critical. No model can capture ALL aspects of a system or process, so only those attributes critical (or thought to be critical by functional experts or policy makers) to the analysis require validation.

Furthermore, in reality, validation is limited to checking a limited number of permutations of the model (to include any "unique" or extreme cases) to infer the validity of the model in the generic sense. The most common type of validation for system dynamic models is "face validation," or thorough various means ensuring agreement that the model's structure, processes, parameters, and results seem appropriate.[82] Rather than rely solely on one or more experts to validate the results of the model, this dissertation will also employ three tests to ensure validity: Are the results consistent with established economic theory, commercial examples, and the demonstration at the ALC? If the results of this model meet these criterions, the model will be considered a credible representation of the PSM process as it relates to the operations within the ALCs. In the initial testing of the model, the failure of one or more of these validation checks will drive additional analysis to determine if the comparison is valid, if the model is correctly designed, or if the "established" case studies or economic theory has been miss-interpreted. Failure to correctly account for this failure though revisions to the model or a better understanding of the economic theory will discredit the model and the analysis.

While not an explicit part of the verification and validation process, any evaluation regarding the policy relevance of the model must take into consideration the magnitude of the potential improvement with respect to the size of the change to the existing operating environment. Although changes in a particular policy lever or set of levers may result in a slight performance improvement, if the size of this improvement is not significant then policy makers will have little incentive to implement change. Thus, for the model to make a relevant policy recommendation the potential for improvement must outweigh the cost and risk associated with changing from the status quo. While there is no formal test for the size of change needed to be relevant, specific policy recommendations must take into account the size of the change in measures of interest and the significance of the change.

Finally, the degree to which a model must reflect the system being modeled depends upon the use of the model. Models used to predict the status of individual parts must have a higher degree of fidelity than models intended to understand the overall PSM process. As the model developed in this analysis is

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[82] Ibid, p. 382.

intended for the latter, its ability to predict the status of each individual part is not critical, limiting the need for detailed validation of the performance of individual parts.[83] At this time during the development and initial exploration of the PSM model, the validation of the model is limited to validating its structure with further study needed to validate the functional form and parameterization of many of the individual links within the model.

With the utility of system dynamic models documented, this analysis can now proceed to the actual development of a model of the PSM process used by the Air Force. Prior to describing the operation of the model, a discussion of its design and contents is provided in Chapter 4.

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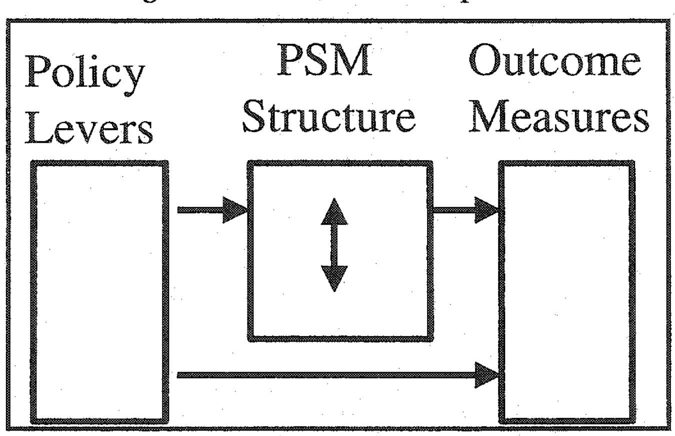
[83] As noted by James Hodges, models that cannot be fully validated can still serve as usefully policy tools. In particular, this dissertation develops a model that can be used to as a decision aid rather than to predict the specific support arrangement for each individual part. Hodges, James S., "Six (or so) Things You Can Do With a Bad Model," *Operations Research*, Vol. 39, No. 3, May-June 1991, pp. 355-365.

4. PSM Levers, Measures, and Model Development

This chapter explicitly describes how the PSM process is captured in a system dynamic model. As shown in Figure 10, the model has three primary components: A set of PSM policy levers, the intermediate PSM structure used to represent the PSM process, and a set of outcome measures capturing items of interest to policy makers. Before describing the model building process, the specific objectives or outcome measures used to evaluate the effect of different configurations of policy levers are developed and described. The chapter then documents and defines the specific PSM policy levers to be modeled. This discussion includes a definition of the levers and the ranges of appropriate values both in general and as they relate to the F100 engine data. As seen in Figure 10, these levers can affect outcome measures directly or through the PSM structure. Details on how the model operates can be found in Appendix A. With an explicit understanding of both the inputs (policy levers) and outputs (objective measures) of the model, its design is then considered. This includes an analysis of how well the model represents not only the PSM process but also the operations at the Oklahoma City ALC supporting the F100 engine.

Figure 10: PSM Model Components



With an understanding of how the model is developed, the utility of developing such a model to assist in the debate of how the PSM process operates is examined, to include the ability of the model to document to decision makers the intricacies of the PSM process. The chapter concludes with a critique of the model, identifying any limitations either in the model as written or of models in general to accurately capture the critical aspects of the PSM process.

Measures of Improvement

Before defining what changes can be made to the PSM process through the adjustment of various policy levers, the objective measures of improvement must be explicitly defined.

The nature of the logistics system that the PSM process supports, (customer requirements, industry dynamics, etc.), as well as the overarching objectives of the organization, must be considered when developing a set of performance metrics for selecting or evaluating the design of a PSM process to source a particular set of parts. For example, a stable, efficient logistics system with a cost efficient PSM process is desired as part of the logistics system supporting a highly automated and cost conscious industry (such as the manufacture of a commodity with a stable source of raw materials and a stable demand like the production of steel). However, an industry that is highly turbulent and subject to frequent changes (such as the demand for computer chips) requires a different more flexible and responsive type of support strategy. Developing the proper goals and objectives of any support process, such as the PSM process, must consider the overarching objectives of the organization being supported.

Overarching Objectives

The primary objective of the military is to support the national security strategy of the United States. The role of support agencies that perform PSM functions are captured in the overarching concept of Focused Logistics, [84] defined by the Joint Chiefs of Staff as "providing the right equipment and supplies in the right quantities to the right place and time."[85] The actual implementation of Focused Logistics in the Air Force rests upon three fundamental precepts:[86]

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[84] The Department of Defense is currently shifting away from the concept of Focused Logistics, to a more adaptive system coined "sense and respond logistics." This new concept stresses the need to quickly react to changes in requirements. While this change may alter the doctrine of the DoD, it parallels the Air Forces concept of Agile Combat Support and should not alter the set of outcome measures developed in this analysis. For more information on the concept of sense and respond logistics see: Cebrowski, Arthur K., Director of Force Transformation, Office of the Secretary of Defense, transcript of interview with *Information Technology Association of America*, August 1, 2002. Online at: http://www.oft.osd.mil/library/library_files/article_5_final_itaa_answer_1.doc (as of June 26, 2003).

[85] U.S. Joint Chiefs of Staff, *Joint Vision 2020*, Washington, Joint Chiefs of Staff, 1999, p. 24.

[86] Handy, John, Lieutenant General, DCS for Installations and Logistics., in *FY 2000 DoD Logistics Strategic Plan*, Deputy Under Secretary of Defense (Logistics), August 1999.

1. The role of expeditionary aerospace operations stresses a flexible system that is integrated, mobile, and precise to meet the evolving requirements of the warfighter.

2. Current resource constraints necessitate an Air Force logistics system that provides the required performance and is both affordable and effective.

3. Eliminating barriers and optimizing process efficiency enhances customer confidence. This allows them to reduce forward deployed inventory and further improve the performance of the sustainment system.

Within the legal and social requirements, such as the need to support small and disadvantaged businesses, requiring the PSM system to be flexible, affordable, effective, and customer focused summarizes the precepts of Focused Logistics. These are the goals that any initiative must strive for when reforming the Air Force PSM processes. The following sections will describe how this dissertation defines these concepts.

However, unlike a commercial enterprise's clear objectives of maximizing both short and long-term profits, the goals of the government are more complex. Government agencies must be concerned about the efficient use of tax dollars as well as the social effects of their purchasing practices. Therefore, when developing the desired output measures (or metrics) the Air Force must consider both the social effectiveness and economic efficiency of the process.

Balance is required

The actual process needed to achieve the goals of Focused Logistics is operationalized in the Air Force as Agile Combat Support. This support plan recognized both the inherently military nature of the task as well as the need for maximum flexibility. To ensure that all aspects of performance are considered when evaluating a change proposal to support this plan a balanced measurement system is needed.[87] Without an integrated set of measures, a single aspect of performance such as cost will dominate the decision-making process at the expense of other equally critical outputs such a delivering a quality product, having enough parts available when needed, etc. The goals of the logistics transformation discussed earlier flow from the concepts of Focused Logistics and Agile Combat Support. The objectives of this transformation are met when the

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[87] Brewer, Peter C. and Thomas W. Speh, "Using the Balanced Scorecard to Measure Supply Chain Performance," *Journal of Business Logistics*, Vol. 21, No 1, 2000, pp. 75-91.

performance of the system is improved without significantly increasing the total cost of that support.

Kaplan and Norton formally developed the concept of a Balanced Scorecard - an approach to conflicting objectives (i.e. performance versus cost). This basic Balanced Scorecard approach developed by Kaplan and Norton has been adapted to a variety of settings and industries to include the DoD.[88] They have four categories of measures in their version of a Balanced Scorecard: financial, customer, internal business, and innovative and learning.[89] Within the DoD logistics environment, some categories receive more attention than others. Within limits, internal business efficiency is less important than meeting customer requirements (effectiveness) and these two "performance" categories are combined for the purposes of this analysis. Similarly, innovation and learning asks what a commercial enterprise must do to retain customers, and maintain a competitive edge in the marketplace. This, of course, is not a primary issue for government agencies whose top priority is customer/warfighter satisfaction. The operating efficiency or innovativeness of the system is critical to performance in the commercial sector, where enterprises will opt to leave an inefficient market or abandon an outdated product line. However, within government operations, where for the purposes of providing logistical support, the types of weapon systems supported are given, limiting the ability to shift to a more efficient product line (weapon system). Consequently, human resource issues regarding the impact of changes on the workforce and the ability for the existing structure to adapt to any proposed changes in policies or procedures are captured in the model developed in this dissertation as a "cost" of implementing any changes to the existing system. Therefore, the specific evaluation criteria included in this model fall into the two categories of performance improvement (or operational effectiveness) and cost reduction (Figure 11).[90] As modeled changes to the process must balance these two competing objectives. The specific factors captured in each of these two overarching objectives are discussed in

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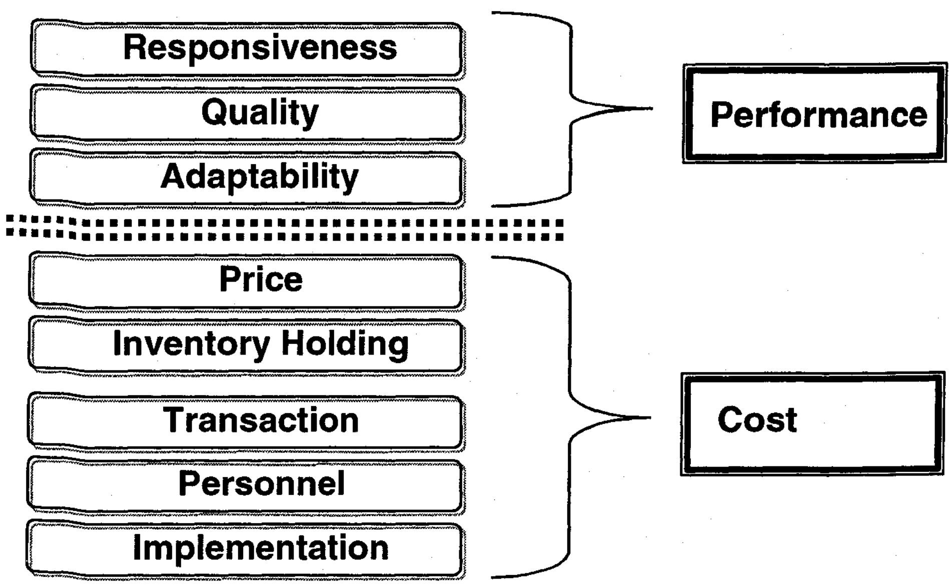
[88] Within the DoD the logistics Balanced Scorecard initiative is working to adapt the approach of Kaplan and Norton to the overall logistics process. See: U.S. Department of Defense, Office of the Assistant Deputy Under Secretary of Defense, Logistics Systems Management, *The Department of Defense Logistics Balanced Scorecard Initiative*, Version 1, June 26, 2003. Balanced Scorecards are used at all levels of the DoD to include the establishment of scorecards at the Air Force, Major Command, and unit levels. For an example of the Balanced Scorecard being developed as part of the PSCM IPT at HQ AFMC see: Tinka, Marie and Scott Correll, " Improving Warfighter Readiness Through Purchasing and Supply Chain Management (PSCM) Transformation," HQ AFMC, PSCM IPT briefing, June 2003.

[89] Kaplan, Robert S. and David P. Norton, "The Balanced Scorecard – Measures That Drive Performance," *Harvard Business Review*, January-February 1992, pp. 71-79.

[90] Porter, Michael E., "What is Strategy?" *Harvard Business Review*, November-December 1996, pp. 61-78.

more detail in the following sections and a more detailed description of how the various measures are weighted and combined into these summary measures is contained in the discussion of the decision support system in Chapter 5.

Figure 11: Evaluation Criteria



Performance Improvement

To ensure that the level of support provided to the warfighter is improved (or not significantly reduced) from a variety of aspects, this analysis monitors three measures of performance: responsiveness, quality, and adaptability. Each of these measures of improvement are discussed in more detail below:

<u>Responsiveness</u>

This measure captures the degree to which the PSM system achieves the ultimate objective of meeting the customer's needs, as they are currently defined. The "best" PSM process relative to this measure would seek to provide the types and quantities of items the customer needs rather than just seek to operate with internal efficiency and effectiveness. For the PSM process, the customer is defined as the user of the items procured.

Responsiveness is the primary measure of how well the PSM process is meeting the customer's requirements, by tracking three sub-measures: issue effectiveness, average customer wait time, and average back order. Customer wait time,[91] or the average time (in months) from receipt of the customer demand to the delivery of the part from the ALC, represents the single most important metric of the PSM process.[92] However, in addition to the average wait time these other aspects of responsiveness are also of interest. Issue effectiveness represents the percentage of the time that the customer receives a part in the same period it was demanded. Stated another way, this is the percentage of the parts delivered when demanded with no delay due to shortages in inventory. The final metric within the category of responsiveness is the average back order time, or the average age of backorders relative to the average demand. This sub-measure reflects the size of the inventory needed at the base, on average, to account for issue delays. This measure unlike customer wait time is sensitive to the length of the delay only for those parts not immediately issued. Together, this suite of three metrics balances the ability to meet current and historical demands in a single consolidated measure of the PSM processes responsiveness to customer requirements.

Quality

The optimal supply strategy should provide the right, high quality parts when and where needed. Performance evaluation should include not only measures of how well the alternative provides parts (responsiveness) but also the system's ability to provide the right part -- not just the correct part number but a physical item that fits all of the desired characteristics to include those not explicitly defined. Part quality, or the ability of the supplier to meet contract specifications, through the sub-measure of percentage of parts that are received with some type of defect, is the most important quality sub-measure and is weighted heavier than the other three sub-measures. However, some characteristics of an item are difficult to quantify or omitted during the quantification of contract specifications as they were not considered important. For example, the smoothness of a part's surface may not seem critical if historically all parts were delivered relatively smooth, but unless explicitly

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91 The Department of Defense has an instruction dedicated to the definition and implementation of customer wait time as a DoD wide measure. U.S. Department of Defense, *Customer Wait Time and Time Definite Delivery*, DoDI 4140.61, December 14, 2000.

92 Virtually all the personnel at Oklahoma City ALC reinforced this fact. As the objective of the PSM process is to provide parts to the users of those parts, the speed with which these parts are sourced and delivered is critical and tracked at all levels of management from CWT of individual items to the average CWT Air Force wide. Because of this importance, when combining the three metrics into the measure of responsiveness the metric of customer wait time is given significantly more weight than the other measures of issue effectiveness and average backorder time. The specific weights assigned to each measure during the execution of the PSM model using F100 engine parts and how these weights can be adjusted as desired is discussed in Chapter 5.

specified parts with large burs or sharp edges would meet formal specifications but could result in a safety hazard when handled. These "soft" or unspecified attributes can be important to the customer. Strict contractual agreements between enterprises often fail to properly capture them because the criticality of a particular attribute may not be known when the initial contract requirements are established. These indirect quality attributes of each part are captured by the sub-measure of the percentage of certified suppliers. Suppliers with certified procedures (e.g. ISO 9000 certification) will in general produce parts with higher quality and consistency, increasing the likelihood that these soft attributes are present. These supplier unique characteristics, while difficult to quantify, can be important to the usefulness of the part provided.

The other aspect of quality captured in this outcome measure is the quality of the contracting process used to award and modify contracts.[93] This is captured by the final two sub-measures of contract award time and ease of modification. An efficient award process, not only makes contract adjustments easier to write, decreasing the cost and improving the quality of these transactions, but efficient business practices make it easier for suppliers to conduct business with the Air Force. This is particularly important when working with small and disadvantage businesses that may not have the experience and expertise of larger, well established enterprises.

Together these four sub-measures, percent defective parts, percent certified vendors, average contract award time, and ease of modification capture both the need for quality parts and the desire to have effective business practices.

Adaptability

The final performance aspect included in the analysis measures how flexible the system is to changes in requirements or operating conditions. Unlike some traditional manufacturing industries where there may be a stable demand for items, the after market support of major weapon systems is a much more complex and variable environment.[94] Unplanned failures of existing

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[93] While ease of modifying contracts and contract award time are related to the adaptability of the PSM process, these metrics could also have been placed under the outcome measure of adaptability. They are included as quality measures because they are not directly measurable as a specific percentage of parts with inventory or the other adaptability metrics. It was decided to keep all "soft" quality attributes in one category to highlight the importance of these metrics that are often overlooked when "optimizing" the performance of a peacetime logistical support process.

[94] Oklahoma City ALC personnel felt this variation in demand was a major factor that must be considered when designing a support strategy. Due to the non-linear nature of the demand for engine parts, any PSM process must be capable of adapting to new and unplanned demands. For a more in-depth discussion of how demands for aircraft spare parts vary see: Crawford, Gordon,

components drive demands rather than production schedules determined in advance. Adding to this variability, the defense industry must be capable of supporting a wide variation in demand levels with changes in mission requirements. Changes in demand for specific parts can come from the normal variation in the demand for parts to support the operation and training of the armed forces or more non-traditional sources of increased demand such as contingency operations or a major war. The need for this non-seasonal type of flexibility is not present in most civilian industries except during rare events and represents a unique challenge that the Air Force must consider when evaluating support strategies.

To capture both the ability to handle unanticipated requirements in the future as well as the ability to adapt and recover when demands are higher than anticipated, this category is composed of three sub-measures. The average surplus tracks the number of months the average demand can be met with existing inventory, while the percentage of parts with inventory reflects parts having at least one item left in inventory at the end of the month. These two measures track the ability to handle a surge in demands as well as the ability to handle a single unanticipated demand. The final sub-measure tracks the response time or the number of months needed to source a part that is not initially available. This sub-measure indirectly captures the opportunity cost of having end items unavailable for use due to a lack of parts. In the DoD, where the quantity of a particular weapon system is fixed in the short run by the acquisition process, it is not possible to simply buy more end items (aircraft or whole engines) to offset a decrease in mission capable rates. This is particularly important when purchasing weapon system parts that in general have long production lead times. Adaptability does not capture the total cost of these lost opportunities, but it does capture the relative differences between the various strategies to ensure that weapons systems are available when needed.

Cost Reduction

As indicated earlier, in today's post Cold War era budgets for defense are even more constrained. Thus, while not an explicit factor in providing Agile Combat Support, the ability of a strategy to reduce (or at least contain) costs is critical. As noted by the Under Secretary of Defense for Acquisition, Technology, and Logistics, "Our acquisition and logistics support cycles are too long and our

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Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications, Santa Monica, Calif,: RAND, R-3318-AF, 1988.

cost overruns are too often."[95] It is critical that the cost of support not increase (and ideally be reduced) from the current levels. For this analysis, costs that are relevant to the performance of the PSM process have been divided in to four different categories.[96]

Unlike some performance measures that have no explicit unit of measure, costs are counted in dollars. To highlight the fact that changes in a particular cost category have both an absolute value, in dollars, but also must be compared in relative terms to the baseline case, measures in cost categories are tracked as both for the percentage change from the initial "baseline" condition, in which none of the PSM levers are adjusted, as well as the total change in costs in dollars. Because the Air Force does not explicitly track costs in many of the cost categories captured in the PSM model, the exact dollars value assigned to savings in a particular category is not known with great certainty. To highlight the magnitude of changes in the various cost categories rather than the specific cost of a particular scenario, when reporting the results of the model in later sections of this dissertation, costs are reported as a relative percentage shift by category. This provides decision makers with a better understanding as to the scope of cost savings possible with different configurations of the PSM policy levers.

Price

The largest single cost category is the actual amount of money paid to the supplier to purchase the parts. As an explicit part of each contract, price is the easiest cost category to quantify, but does not include all of the costs associated with the purchase and delivery of spare parts. In addition to this category, other indirect cost categories represent as much as half of the total cost of ownership (also known as the life cycle cost) and must be included to fully capture the effect of any policy change.[97] For the data set used in this

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[95] Aldridge, E.C. "Pete," Under Secretary of Defense for Acquisition, Technology, and Logistics (USD, AT&L),. Congressional Hearings on Fiscal Year 2002 National Defense Authorization Budget Request, House Armed Services Military Procurement and Military Research and Development Subcommittees, July 12, 2001.

[96] As noted earlier, while it is recognized that there are costs associated with implementing any changes to the existing PSM process, these one time costs do not alter the recommended long-term configuration of the PSM process and are excluded from this analysis.

[97] Chapman, Timothy L., Jack J. Dempsey, Glenn Ramsdell, and Michale R. Reopel, "Purchasing & Supply Management: No Time for 'Lone Rangers'," *Supply Chain Management Review,* Winter 1998, pp. 64-71.

dissertation, the latest acquisition price of each spare part collected by the Air Force as part of the F100 PSM demonstration at Oklahoma City ALC.[98]

Inventory Holding Costs

The cost of holding parts from when they are purchased to when they are actually used is another easily captured cost category that is often the target of cost reduction initiatives. These costs can be incurred by the Air Force holding an inventory of finished parts, or by suppliers holding an inventory of parts or components to meet the demands of the Air Force within an agreed upon delivery time. In addition to the actual physical storage or warehousing costs, this category indirectly represents the cost of having parts break, become damaged, or become obsolete while in storage. The average cost of holding inventory, beyond the basic warehousing costs, is not known within the Air Force and varies with the type of component being stored.[99] This analysis assumes it is composed of a per unit cost that varies by category (i.e. different size parts take up more space and can cost more to hold), but is also a function of the part's purchase price (to include the opportunity cost of tying up capital in parts not needed). For example, a turbine blade may cost several times more than a large structural assembly, but takes up less storage space. Thus as a category of parts, blades would have lower holding costs per unit but higher opportunity costs associated with their higher price.

Transaction Costs

The final explicit cost associated with acquiring a part is the transaction cost of buying the part, getting it from the supplier to the customer, and personnel participating in supplier development efforts. This includes the cost of marketing, research, offering and awarding the contract, maintaining the contract, monitoring suppliers' performance, as well as the physical effort required to pick, pack, and ship the parts. This "administrative" cost can range from as little as 4.3% for many commercial companies to a median value of 10.2%

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[98] Price and other attributes for all active Air Force managed F100 parts was provided to RAND for use in this dissertation as well as other RAND projects. Detailed information regarding the contents of these files is provided in Appendix B.

[99] While DLA tracks the cost associated with maintaining warehouse space for all spare parts, this cost is not tracked by the type of part. Additionally, during discussions with personnel from the Oklahoma City ALC it was not possible to determine the cost of replacing damaged items or items that break due to age. Rather than attempting to model discrete failures of parts being held in inventory, it was determined that inventory holding costs in the base case would be about 0.5% of inventory value and that this percentage would rise to 0.6% if inventory levels were doubled.

for the defense and industrial community.[100] Inefficiency in the operation and management of the procurement system increases costs and can adversely affect performance. As noted earlier concerning the scope of this dissertation, the cost of determining what parts to buy (i.e. requirements determination) is not part of the model presented here. The decision to repair the existing part or to manufacture the part internally vice purchase a new part from a supplier (i.e. make versus buy) is also not part of the PSM process under consideration. It is assumed that the make or buy decision has already been made, and transaction costs reflect the costs associated with implementing the decision to buy a new part by finding a source, securing a contract, and administering that contract (placing the order for a part).

Transaction costs are composed of three sub-measures: contract award costs, delivery order costs, and supplier development costs. Contract award costs and delivery order costs represent the cost of awarding all contracts (and delivery orders) at the average cost per award (order), which changes with modifications to various policy levers. Supplier development costs reflect any increased costs, other than the increased use of Air Force personnel, of supplier development efforts which also vary by changes in various policy levers. Data to populate these measures was provided by Oklahoma City ALC, and reflect the cost of conducting business using their current procedures. For example, they estimate that the average cost of awarding a contract is currently $500, and that it costs about $10 to process a delivery order for each part ordered in a given month.[101]

Personnel Costs

One of the most significant but overlooked cost categories is the cost of manning the process. This includes Air Force personnel to award contracts and place delivery orders as well as manage the suppliers and the supply base. In many cases, these are considered part of the transaction costs but due to their criticality and the propensity of many cost reduction efforts to reduce personnel manning levels, these have been identified as a separate cost category. This includes contracting personnel and parts managers as well as the support staff of

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[100] Performance Measurement Group (PMG) 1999-2000 Benchmarking Series. Online at www.pmgbenchmarking.com (as of November 12, 2002).

[101] The costs of awarding contracts and ordering parts both increase exponentially with increases in the price of the contract (order). This is based on the assumption that as the price doubles, not only will the award costs increase, due to additional levels of review, but that these additional reviews must be coordinated with existing reviews further increasing award costs. The functional forms and parameters used in the model were estimated but were not found to be significant to the performance of the model.

engineers, financial managers, inspectors, etc. needed to provide the parts to customers. While attempting to capture all of these costs explicitly in a model is quite difficult, some consideration needs to be given to the variation in the number of personnel (both military and civilian) needed to support the system when comparing alternative structures.

This module explicitly captures the indirect personnel costs incurred by the Air Force to operate and support the PSM process, in three sub-measures: the number of employee equivalents needed to award contracts, cut delivery orders, and work with and monitor the performance of suppliers. The data used to model this cost category was provided by personnel at the Oklahoma City ALC. For example, it is estimated that in the current process it takes about 2 hours to oversee each supplier each month with an average cost per employee of $60,000/year.

Policy Levers

With an understanding of how the performance of the PSM process is to be judged, the attention now focuses on how performance will be altered. Specifically, what policy levers are available to change the structure or operations of the PSM process to improve performance or reduce costs?

The concept of PSM involves the integration of the purchasing and supply functions, as well as the development of strategic relationships with key suppliers. To achieve the most efficient and effective design of this process several policy options (or levers) are available and captured in the model of the PSM process. Each of these policy options affect both the cost and performance of the supply base and may or may not need adjustment (i.e. altering the degree to which supplier development efforts are undertaken or changing the size of the supply base), depending upon the nature of the parts being sourced and the business environment in which these parts are produced. The eight policy levers included in this analysis and ways in which this model assumes they impact the PSM process are summarized in Table C and described below.[102] A more detailed discussion of these assumed relationships is contained in Appendix C.

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[102] While there are potentially additional levers that could be included in the design or alteration of a PSM process, after reviewing the commercial and academic literature, and discussing which levers to include with several Air Force personnel it was determined that this list represented all levers that are likely to have a significant impact on the PSM process.

Table C: PSM Policy Levers

Policy Lever	Assumed Effects
Number of Suppliers	More will ... - Increase the number of delivery orders - Increase contract administration costs - Increase the percentage of defective parts - Increase the cost of supplier development - Alter the price of each part
Number of Contracts per Supplier	Fewer will ... - Increase individual contact award time - Decrease total contract award costs - Increase ease of modifying requirements - Reduce the effectiveness of performance measures - Reduce the price of each part
Supplier Development	More will... - Increase cost of working with each supplier - Reduce the price of each part - Decrease the time required to monitor each supplier - Increase individual contract award costs - Increase the percentage of certified vendors - Decrease the percentage of defective parts - Decrease production lead time
Inventory Levels	Higher inventory levels will ... - Increase inventory holding costs - Increase the percentage of defective parts
Length of Contract	Longer contracts will ... - Increase contract award time - Increase individual contract award costs - Increase time required to monitor individual contracts - Decrease time required to monitor each supplier - Decrease administrative lead time - Decrease the percentage of defective parts
Joint Forecasting	More joint forecasting will ... - Increase the cost of placing orders - Decrease production lead time - Increase time required to monitor each supplier - Decrease the time required to place orders
Performance Measures	Increased use of performance measures will ... - Increase contract award time - Increase individual contract award costs - Increase the cost of placing orders - Alter the price of each part

	- Decrease production lead time - Decrease the percentage of defective parts
Integrated Product Teams	More extensive use of teams will ... - Increase individual contract award costs - Increase contract award time - Increase the effort of placing an order - Increase time required to monitor individual contracts - Decrease the percentage of defective parts

Number of Suppliers

This policy lever reflects the number of suppliers that the Air Force considers as part of the actual "bidding pool" for a given part. While this maximum number of available suppliers may not all be on contract at the same time, having a larger set of suppliers will, in general, increase the number on contract at any given time. The number of suppliers can be no larger than the number of qualified suppliers in the market place. However, the Air Force may choose to restrict the number of suppliers with which it does business, in which case the number of suppliers will be less than the number of qualified suppliers in the marketplace. It is assumed that in selecting this limited supply base, those suppliers who provide the best quality and value to the Air Force will be selected (See appendix A for more details on this and other assumptions used in developing this model). Fifty nine percent of the parts in the sample data of the F100 parts have only one source of supply. Having only one source for many parts limits the overall potential for supply base reduction, reducing the ability to greatly reduce the number of suppliers. However, the supply base can be reduced further by restricting business to a smaller set of select or "preferred" suppliers for parts with multiple sources (i.e. the Air Force could decide to source a particular part from only one supplier despite having multiple qualified sources for the item). In addition to reducing the cost of managing the supply base (with fewer suppliers), by retaining only the top performing suppliers supply base reductions can simultaneously improve part quality and supplier responsiveness while leading to lower prices through volume discounts.[103]

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[103] While traditional economic theory suggests that increased competition will lower prices and improve quality, modern transaction cost economics recognizes that while more suppliers reduces the prevalence of monopolistic forces; economies of scale can make markets with fewer participants more efficient. Through increased buying power associated with a larger volume of business with remaining suppliers can result in lower prices and better performance. Cox, Andrew., Joe Sanderson, and Glyn Watson, "Supply Chains and Power Regimes: Toward an Analytic Framework for Managing Extended Networks of Buyer and Supplier Relationships," *The Journal of Supply Chain Management*, Spring 2001, pp. 28-35. For additional references supporting the benefits of reducing the supply base see: Hahn, Chan K., Hyoo H. Kim, and Jong S. Kim, "Costs of Competition: Implications

Within the PSM model, this lever is represented by a parameter that reflects the size of the future supply base as a percentage of its current size. As the Air Force currently has very limited efforts to reduce the supply base, it is assumed that no increases from the current number of suppliers are possible. Values explored in the model range from no change or keeping 100% of current suppliers, to reducing the supply base to 20% its current size where possible.[104] For example, if there are currently two suppliers, reductions of less than 25% will result in no change in the number of suppliers sought (2*.75=1.5 which rounds back to 2). Reductions greater than 25% will reduce the number of suppliers the Air Force chooses to conduct business with to one, regardless of the extent of the reduction (at least one source of supply is kept for each part). As noted earlier, the actual possible reduction depends upon the number of suppliers for each individual part.

Number of Contracts per Supplier

Having multiple contracts with each supplier increases the total cost of maintaining these contracts but may also allow for more customized contracts that improve performance. However, if similar parts purchased from a single supplier are on separate contracts due to a lack of coordination and planning, combining the requirements into one contractual document will reduce administrative costs. For example, it is estimated that it costs $500 to award a simple one-item contract. Awarded separately contracting for two items would cost $1000, but by combining the two items into a single contract the larger contract would cost more than $500 to award but less than $1000 as only one set of contract terms and conditions need to be written and negotiated with suppliers.[105] Larger contracts also improve the buyer's leverage with suppliers, potentially improving contract terms for cost and performance.[106] In the historical data used to populate the PSM model regarding the number and size of

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for Purchasing Strategy," *Journal of Purchasing and Materials Management*, Fall 1986, pp. 2-7. and Ogden, Jeff, "Supply Base Reduction Within Supply Base Reduction," *Practix*, Volume 6, January 2003.

[104] While further reductions are possible, the current data set has at most five suppliers for a single part. An 80% reduction in the supply base essentially leaves only one source for all parts making further reductions impossible.

[105] The model currently assumes that if the targeted number of contracts per supplier is reduced by 50%, the cost of awarding all contracts is reduced by 10%. This relatively small reduction acknowledges the fact that in many cases, it is not possible to combine dissimilar parts into a single contract, due to the unique contract terms required and that many suppliers currently have only one contract with the Air Force.

[106] Phillips, Cheryl L. M. and V. R. Rao Tummala, "Maximizing Purchasing Synergies," *Practix*, Volume 5 Issue 3, March 2002, pp. 18-21.

contracts used to source F100 engine parts, no consolidation efforts have been attempted, leaving significant room for adjustment to this policy lever.[107] Within the PSM model, this lever is represented by a parameter that represents the number of contracts retained per supplier. In our exploratory analysis, the value of this lever is allowed to range from no reduction (100% retained) to keeping only 20% of the contracts (by on average combining five current contracts into one consolidated contract).[108]

Supplier Development

Supplier development reflects the extent to which the Air Force works with suppliers to improve their capabilities.[109] This includes not only working to improve suppliers' processes, decreasing production costs and improving quality;[110] but also efforts to improve the efficiency of the interaction between the two enterprises, reducing both administrative and production lead times.[111] While the Air Force currently engages in some supplier development activities, these efforts are limited in their size and scope.[112] This lever is represented by a parameter that reflects the relative percentage change in the scope of supplier development efforts; with higher number indicating more prevalent and extensive use of supplier development. As the Air Force currently undertakes only a limited amount of supplier development, this value can also decrease slightly. Within the PSM model this parameter exploration ranges from 0.75 (a 25% reduction in supplier development) to 3.0 (a tripling or 300% increase in the

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[107] In the past several months, the F100 demonstration has begun combining requirements by supplier into larger consolidated contracts. However, this consolidation has occurred after the F100 data was collected and analyzed and any performance or cost changes as a result of this consolidation is not reflected in the base case of the PSM model.

[108] As the Air Force has done little contract consolidation in the past, it is assumed that increasing the number of contracts per supplier is not a viable alternative. This may not be the case for other business areas or enterprises.

[109] For a more detailed discussion of when supplier development efforts are most warranted see: Bensaou, M. and Erin Anderson, "Buyer-Supplier Relations in Industrial Markets: When Do Buyers Risk Making Idiosyncratic Investments?" *Organization Science*, Volume 10, Issue 4, Jul-Aug 1999, pp.460-481.

[110] In addition to significant cost savings, through the use of supplier development efforts with key suppliers Honda was able to reduce defects from 7,000 defective parts per million to between 100 and 200 defective parts per million. Berlow, Marc, "Medal of Excellence: For superb supplier development- Honda Wins!" *Purchasing*, September 21, 1995, pp. 32-40.

[111] It was found that total cycle times in one manufacturing firm could be reduced by 75-95%. Patterson, James L. and J. Dougal Nelson, "OEM Cycle Time Reduction Through Supplier Development," *PRACTIX Best Practices in Purchasing and Supply Chain Management*, Vol. 2 Issue 3, March 1999, pp. 1-5.

[112] This assertion was confirmed during interviews with functional experts at Oklahoma City ALC who indicated that the Air Force currently does little to improve supplier operations or to integrate the business practices of the Air Force and its suppliers.

amount of supplier development efforts undertaken by the Air Force). While additional increases or decreases are possible for this (and other) policy levers, this range allows the exploratory analysis to consider not only minor increases in the use of supplier development, but relatively significant increases as well. This range is large enough to accomplish the model's intended purpose of identifying the direction and relative degree of change recommended for each of the individual policy levers. For those levers in which the model recommends significant increases, the actual increase possible (that makes good business sense) must be determined with further research during the implementation of these findings.

Inventory Levels

This lever reflects the proclivity to hold surplus inventory or safety stock in excess of that required to meet projected demands. Higher inventory levels increase holding costs, but also can improve responsiveness, as more parts are available to meet unanticipated demands. In addition to the basic inventory level needed to meet average demands during the time it takes for additional parts are sourced from suppliers, a level of safety stock is retained to cover variances in demand and/or unanticipated demands. As the percentage of the basic inventory level the model retains for safety stock, this parameter ranges from keeping an additional 10% of the basic inventory as safety stock to doubling inventory and retaining a safety stock level equal to that needed in basic inventory (100% of basic inventory in safety stock). [113]

Length of Contract

This policy lever reflects the average number of years a contract lasts. Longer contracts with additional options clauses for each additional year of contract coverage are harder, more expensive, and time consuming to write; but are re-awarded less frequently.[114] Adding additional years to a contract reduces the uncertainty associated with the source of future purchases, assuring both

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[113] In general, the Air Force does not have a set safety stock level, allowing individual item mangers to determine the level retained for each part. However, to minimize inventory holding costs these levels are generally kept as low as possible.

[114] While the cost per contract is higher, longer contracts allow the contract award costs to be spread over a longer period of time, reducing the net cost of awarding contracts each year.

parties that future purchases will be sourced from this relationship.[115] By committing to a longer-term relationship, suppliers can have more incentives to make quality and cost reduction improvements.[116] Longer-term contracts should also improve the relationship between the Air Force and suppliers as contactors become more experienced and processes become better integrated over time. While individual contract lengths will still vary due to the nature of the markets for each individual part, in the PSM model this parameter reflects the mean contract length for all parts and ranges from 1 to 3 years.

Joint Forecasting

In traditional sourcing efforts, the Air Force estimates the requirement internally and passes this information to contracting personnel for sourcing from suppliers. These requirements are stated in definitive terms and presented to the suppliers as a given. However, an alternative process can be used where the Air Force works with the suppliers to jointly estimate the size of future requirements. Enlisting the supplier's assistance in the forecasting of requirements should improve the accuracy of the forecast[117] and reduce response times: as the supplier knows what the anticipated demands are for a particular part.[118,119] However, this could also increase the cost of the contract, as suppliers may seek reimbursement for their efforts. Unlike inventory levels or numbers of contracts, the prevalence of joint forecasting cannot be quantitatively measured. Therefore, this parameter is modeled as a percentage shift from current limited levels of joint forecasting and ranges from a slight decrease (75% of current effort) to a significant increase to 300% of the current level joint forecasting activity.[120]

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115 For example, awarding a single two-year contract guarantees that the relationship between the Air Force and the supplier will be in place for two years while if two one year contracts were used, the second contract could be awarded to a different suppliers.

116 Steele, Paul T. and Brian H. Court, "*Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness Through the Skills of Purchasing*," London: McGraw-Hill Book Company, 1996, p. 47.

117 For commercial examples of how joint forecasting can improve the accuracy of the forecasts by roughly 12% see: Buxbaum, Peter A., "Psyched Up," *Operations & Fulfillment*, March 1, 2003.

118 Collaborative or joint forecasting is seen as one of the primary methods of reducing cycle times and the disturbances caused by uneven demand patterns. Coyle, John J., Edward J. Bardi, and C. John Langley, Jr., *The Management of Business Logistics: A Supply Chain Perspective, 7th Edition*, Mason, Ohio:South-Western, 2003, p. 579-581.

119 For a discussion of how variances in demands can become exacerbated as they pass back the supply chain without the use of some type of joint forecasting or sharing of demand data see: Lee, Hau L., V. Padmanabhan, and Seungjin Whang, "The Bullwhip Effect in Supply Chains," *Sloan Management Review*, Spring 1997, pp. 93-102.

120 Interviews with functional experts from the Oklahoma City ALC confirmed that the Air Force currently has some joint forecasting efforts underway, but can increase this effort significantly.

Performance Measures

Regardless of the basic contract type, adding performance measures or incentive clauses, if done well, can induce the supplier to perform beyond the basic minimum contractual requirements. The benefit of these additional measures varies. For standardized items not unique to a particular buyer or group of buyers, economic market forces have established efficient methods of production and adding performance measures may add cost with little benefit, but for customized items the use of these types of measures may slightly increase costs but also improve part quality and supplier performance.[121] Finally, for sole source items where the buyer has little or no leverage with the supplier, the payoff from these incentives may be minimal.[122] Like joint forecasting, this policy lever is modeled with a parameter representing the percentage shift from the current usage of performance incentives and ranges from a slight decrease (75% of current effort) to a significant increase to 300% of the current level of effort.

Integrated Product Teams

The final policy lever included in the model reflects the extent to which integrated product teams are used to determine requirements, award contracts, and monitor and manage suppliers and the supply base. Using an integrated product team to design and monitor a contract (or supplier relationship) increases the cost of the relationship, but should improve performance.[123] The extent of the improvement will depend upon the initial conditions, value of the good or service, relative buyer power, and the relationship with the supplier.

This should result in lower delivery times and ensure that supplier have the necessary capacity to handle any surges in requirements.

[121] Use of performance measures requires clear communication regarding the desired outcomes and feedback regarding supplier performance, but can result in improved performance and quality. Fawcett, Stanley E., *The Supply Management Environment, Volume 2*, Tempe, AZ: National Association of Purchasing Management, Inc., 2000, p. 121.

[122] For a discussion on how the nature of the item purchased and the power balance between the buyer and suppliers affect the number of suppliers and the nature of the relationship with suppliers see. Dowlatshahi, Shad, "Bargaining Power in Buyer-Supplier Relationships," *Production and Inventory Management Journal*, First Quarter 1999, pp. 27-35.

[123] When reviewing the use of IPTs in the DoD for the acquisition of new systems, the GAO found that while teams in general worked to improve the performance of the process, the structure of the DoD's environment was not conducive to effective teaming and could be altered to improve performance. This model assumes these structural changes are not made, and IPTs will continue to operate in the current organizational structure and ways. U.S. General Accounting Office (GAO), *DoD Teaming Practices Not Achieving Potential Results*, Report to the Chairman and Ranking Member, Subcommittee on Readiness and Management Support, Committee on Armed Services, U.S. Senate, GAO-01-510, April 2001.

Although the Oklahoma City ALC currently forms internally staffed IPTs for most large contracts, the participants on these teams retain their functional alignment limiting the effectiveness of the teaming effort.[124]

As modeled, IPTs are reactive and limited to the development of contract strategy, the selection of suppliers and the awarding and execution contracts in reaction to the emergence of a requirement to purchase something because there is no stock on hand. To mirror the current practices of the Air Force, the use of proactive commodity councils or other integrated groups to identify requirements and plan for how to best source future requirements was not explicitly included in the scope of this analysis. Thus, this analysis assumes the additional use of reactive IPTs does nothing to reduce the probability that a contract is in place when needed. The Air Force is in the process of expanding the use of proactive IPTs to incorporate these additional tasks,[125] as seen in the literature, the additional use of proactive IPTs for these purposes could reduce the number of unplanned demands and ensure that a source of supply has been identified in advance for most parts.[126] This lever is represented by a parameter reflecting the relative strength and pervasiveness of reactive teaming practices and ranges from 75% to 300% of current efforts.

PSM Model Structure

This section describes how the policy levers and measures of improvement defined in the previous section are incorporated into a model of the PSM process. The key features of the model are outlined to describe how the model was developed. For additional details regarding the design of the PSM model developed in this analysis and additional views of the model's structure, see Appendix A.

As seen in Figure 12, the basic structure of the PSM model is composed of six modules. Each of these modules interact with the policy levers and contain

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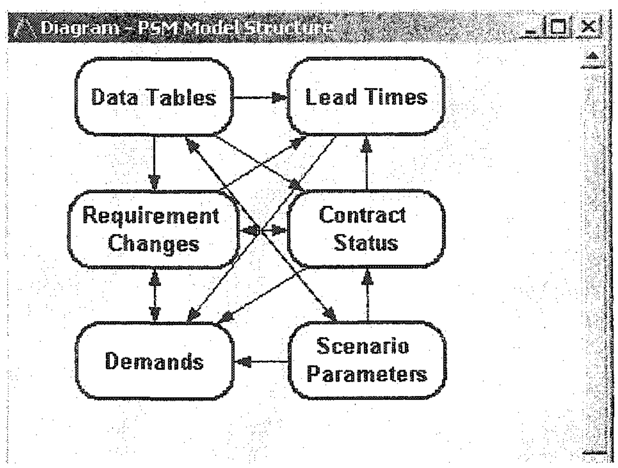
124 This assertion was confirmed by several ALC personnel interviewed.

125 For a description of the Air Force's plans for the use of proactive IPTs called commodity councils in the future see: Tinka, Marie and Scott Correll, " Improving Warfighter Readiness Through Purchasing and Supply Chain Management (PSCM) Transformation," HQ AFMC, PSCM IPT briefing, June 2003.

126 One facet of proactive IPTs is the inclusion of key suppliers in the process in a form of partnership sourcing. The reduction and elimination of shortages is one of the advantages identified with this type or arrangement. Steele, Paul T. and Brian H. Court, "*Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness Through the Skills of Purchasing*," London: McGraw-Hill Book Company, 1996, p. 155.

a representation of a portion of the PSM process used to order and receive parts from suppliers.

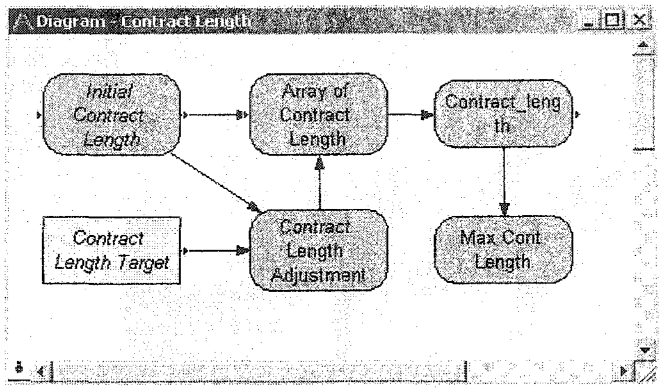
Figure 12: PSM Model Structure



The execution of the PSM model requires data regarding the parts sourced by the PSM process and their individual failure rates, lead times, and contract status. These tables are contained in the data tables module, which must be updated if a new set of parts is to be analyzed using the model. Details on how each of these elements were acquired for the F100 engine parts can be found in Appendix B.

The second component of the PSM structure is the requirement changes module, which translates policy lever changes into a format used by other modules in the model. For example, contract length target reflects the average length desired for contracts for all parts. The contract length sub-module (Figure 13) takes the initial contract length for each part and multiplies it by an adjustment factor needed to adjust the average contract length from its initial value to the targeted value. For example, in the F100 data set the average contract length is 12.1 months. If the contract length target were 3 years, the contract length for each part would be extended 298% and rounded to the nearest month. This preserves the fact that contract periods vary by part but allows the policy lever to alter the average length of time for which contracts are awarded.

Figure 13: Contract Length Sub-module of Requirements Changes

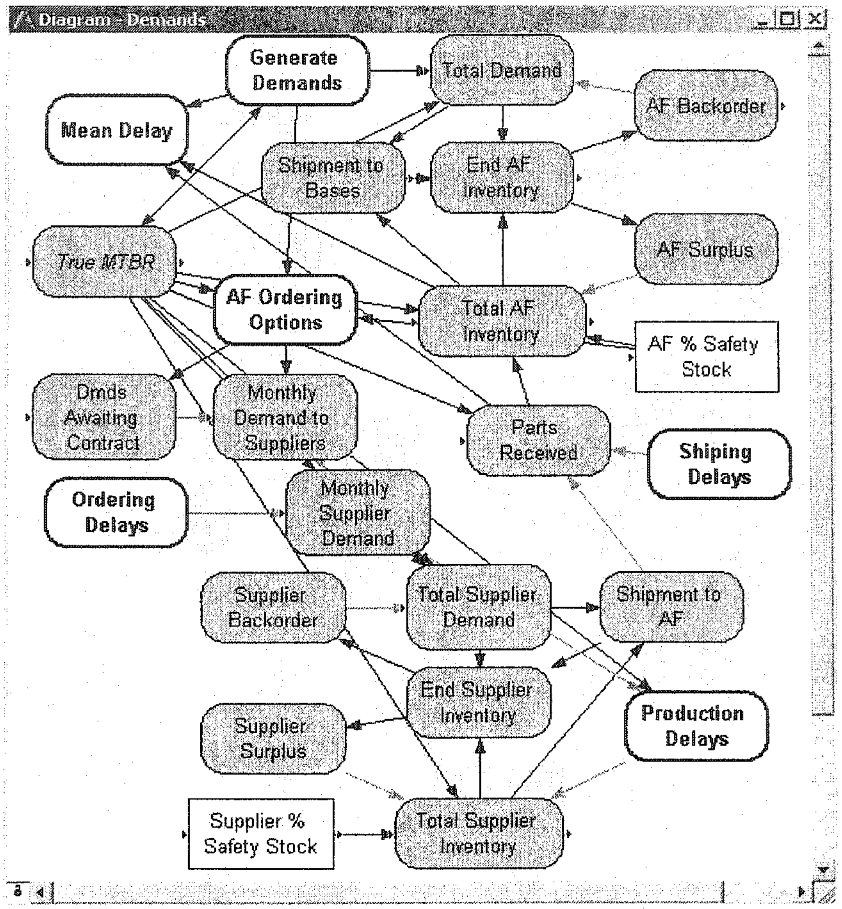


The fundamental part of the PSM model is the process of ordering and receiving parts from suppliers. Thus, the core of the model is the demands module, which replicates the flow of demands from origination to the supplier and the corresponding parts being produced and delivered to the Air Force customer (Figure 14). Demands are generated using a Poisson distribution[127] and either satisfied with existing inventory or placed in a backorder status awaiting the delivery of additional parts from suppliers. Subject to the presence of a contract, orders are placed with suppliers monthly based upon historical demand patterns and the selected ordering methodology[128] after an administrative delay to represent the ordering process. Suppliers, once they receive the order, and either ship parts from their existing inventory or place the Air Force's order in backorder. To meet future orders suppliers begin the production of parts to replenish their inventory or meet backorders, receiving them into suppliers inventory after a production delay that varies by part and changes with various policy levers. Finally, parts are shipped to the Air Force after a final delivery delay and are placed in Air Force inventory to meet backorders or retained to satisfy future demands.

[127] Poisson distributions assume that individual failures are independent random events but occur with some frequency. As most aircraft maintenance actions are unplanned events, this distribution allows the frequency of failures to vary by part in a random manner.

[128] The model allows for three different ordering options to estimate future demands based on historical data using a last period, moving average, or exponential smoothing forecast.

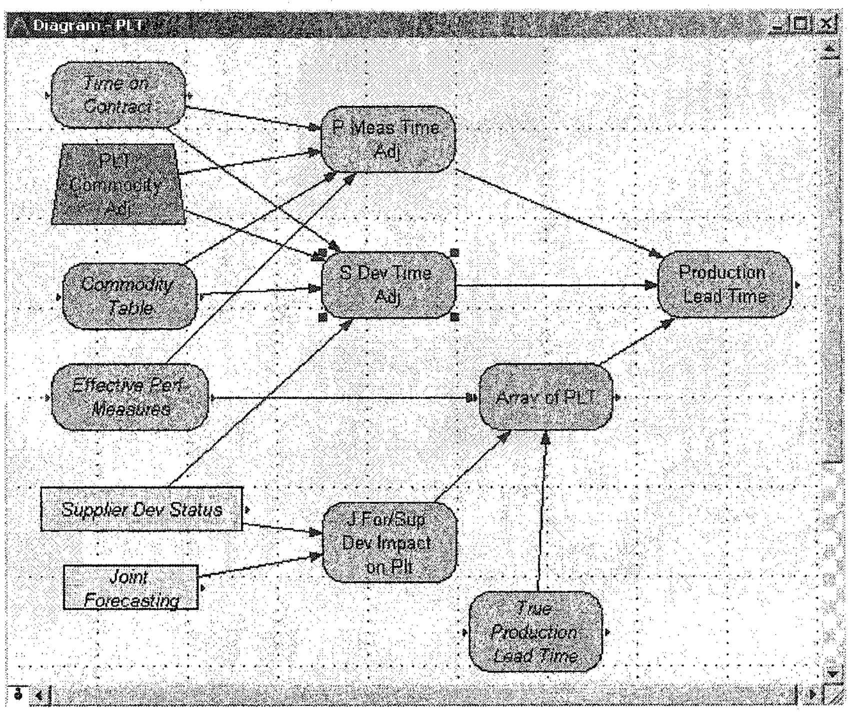
Figure 14: Demands Module



The replication of this physical process of ordering and receiving parts serves as the core of the model and is capable of incorporating not only different demand patterns and part attributes, but can also be adjusted to reflect differences in contract status or changes in the attributes of individual parts over time.

Similar to the requirement changes module, the lead times module adjusts the various lead times (administrative lead time, production lead time, and delivery time) according to the configuration of the policy levers. For example, PLT is affected by the three policy levers the use of performance measures, supplier development, and joint forecasting (Figure 15). In the case of supplier development, PLT is affected in two ways. With increased levels of supplier development, production lead times are reduced in general as more efficient production techniques are learned that can be used for all suppliers and across contracts. However, some of what is learned applies only to the current contractor and as future contracts may or may not be awarded to the same supplier, these improvements in PLT will be lost at the expiration of the current contract (and must be re-learned with the new supplier).

Figure 15: PLT Adjustment by Policy Levers



The general improvements in production lead time with increased levels of supplier development was modeled with an inverse relationship.[129] As seen in Figure 16, in the base case, production lead times are unchanged, while as supplier development efforts increase production lead times are reduced at a decreasing rate. This functional form reflects the assumption that initial reductions in lead times should be easier to achieve and require smaller increases in the level of supplier development. The parameters used in the model, allow production lead times to be reduced by 25% when supplier development efforts are tripled.[130]

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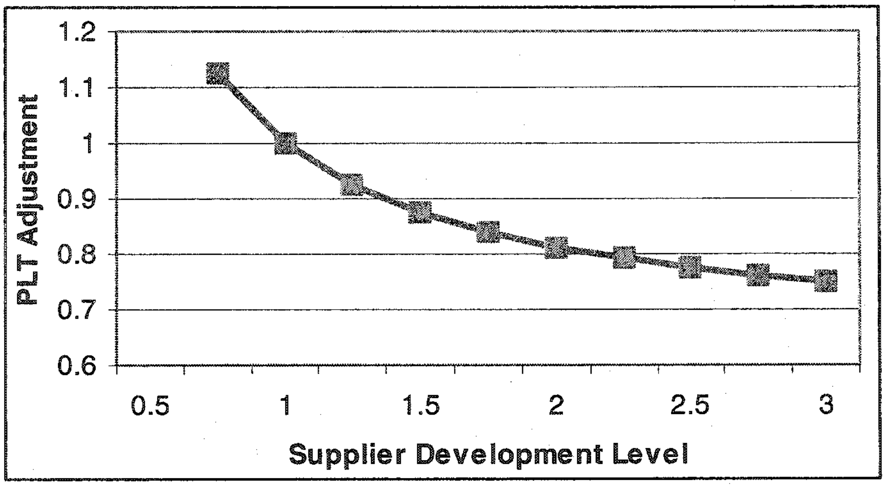
[129] This relationship is modeled using the following equation: Revised PLT= Initial PLT x (0.625 + 0.375/Supplier Development level).

[130] These parameters were chosen to mirror reductions in lead times found by commercial examples. While Trent and Monczka found reductions of about 10%, Buxbaum notes that working with suppliers can result in up to a 60% reduction in lead time. In the current version of the PSM model, reductions are limited to 25% of the initial levels. Trent, Robert J. and Robert M. Monczka, "Purchasing and Supply Management Trends and Changes Throughout the 1990s," *International Journal of Purchasing and Materials Management*, Fall 1998, pp. 3-4. Buxbaum, Peter A., "Psyched Up," *Operations & Fulfillment*, March 1, 2003.

Figure 16: PLT Adjustment with Changes in Supplier Development



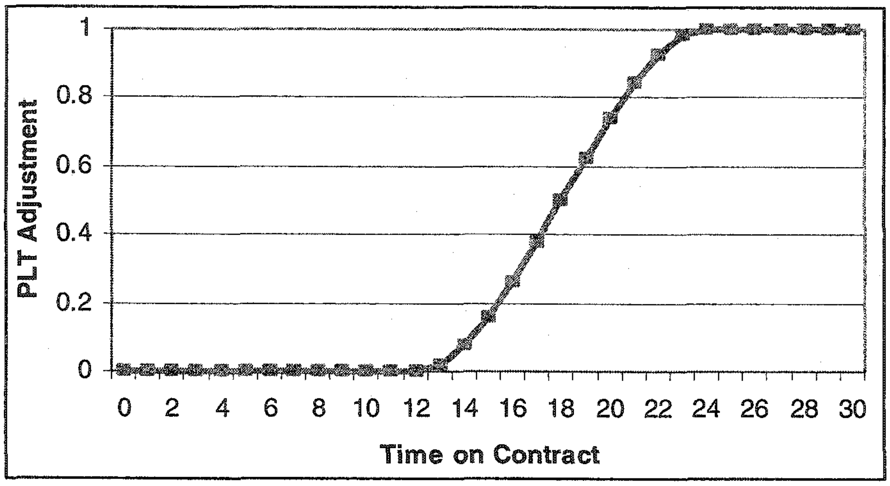
In addition to this global reduction in PLT, further reductions are made as a contract matures. To reflect the assumption that these changes take some time to occur and have a limited scope. As seen in Figure 17, a cubic functional form was used in which reductions to PLT do not begin until the 12th month of the contract and reach their maximum level at the 24th month of a contracts life.[131] This reduction is then calibrated (reduced) based on the complexity of the individual part and the extent that supplier development is used (to a maximum reduction of 30%).[132] This calibration factor is captured in Figure 15, as the table labeled PLT Commodity Adjustment.[133]

[131] For contracts in place less than 12 months, no reduction to PLT was made and for contracts in place for over 24 months the reduction was limited to the maximum possible of 30%. For all months in between the following equation was used to estimate the level of reduction. Adj=[(-1/864)*(Time_on_contract^3) + (1/16)*(Time_on_contract^2) -Time_on_contract + 5].

[132] The use of a maximum reduction of 30% allowed some components to have significant reductions to PLT, but if small reductions are desired for ALL items based on industry data or past experience, all commodity groups can use an adjustment factor to reduce the level of PLT reduction possible with increased use of supplier development.

[133] Based on discussions with personnel from the Oklahoma City ALC, the model assumes the max time decrement is 30% for complex engine components, but production lead times are only reduced at most 6% for basic hardware items such as nuts and bolts.

Figure 17: PLT Adj with Time on Contract



Functional forms for the remaining links were developed using a similar process and parameters chosen either to reflect industry data where available or calibrated with the assistance of the personnel from Oklahoma City ALC to reflect the anticipated changes possible in the current data set. As noted earlier, the refinement of these relationships over time as additional data sets are used to populate the model will improve the overall generalizability of the results derived from the PSM model.

The final step in developing the model was to verify and validate that the model operates as desired. Using the small set of sample data chosen to test the model's performance, a variety of model permutations were analyzed to identify coding errors, mis-specified links, and any unintended interactions of the model's components identified during the analysis of this sample data set. At this time the interface module was built and the model reviewed and redesigned where possible to improve its computational efficiency. Once the model was determined to perform as desired, the actual F100 data set, as described in Appendix B, was inserted into the model for analysis.

The PSM Model Structure Facilitates the Policy Debate

The ability of a system dynamic model to focus the discussion of how PSM policy levers produce changes in performance, and more generally to assist analysts and decision makers in conducting this discussion, is a significant benefit of the model's development and validation. Without ever running the model, merely the presentation of the formal structure of the system proved to be eye-opening to process experts and managers.

Actual model excerpts were used to discuss the scope, design, and operation of the PSM process with experts at RAND and at the Oklahoma City ALC. The system dynamic model pictorial representations served as the centerpiece of the discussion. Providing an actual display of the interactions under consideration proved to be an effective means of ensuring that all participants in the discussion were focused on the same portion of the process.

Similarly, using actual model extracts to build presentations to mid and upper level managers focused the discussion on the design of the PSM process, avoiding the historical reliance on anecdotal evidence from past experiences that may or may not be relevant to the current PSM process. Using actual model extracts avoided the need to develop an alternative display mechanism (such as independently generated charts or graphs) to present the model's design, and kept the discussion on the PSM process. This avoided the need to "translate" the model to management. It ensured that everyone saw exactly how the model captured the salient features of the PSM process. For example, when a manager questioned if the analysis captured a certain aspect of the PSM process they felt was particularly relevant, the presence (or absence) of this feature was immediately apparent, as all portions of the model are available for discussion not just those for which separate visual aides had been developed. The fact that additional effort was not required to translate the model into a format suitable for presentation not only saved time, it allowed for a more interactive discussion to include aspects of the model not initially deemed critical, but which were raised during the discussion.

When reviewing the model with technical personnel from the Oklahoma City ALC, the ability of everyone to examine the specific details regarding the precise interaction of the various components was also a useful feature. Rather than limiting the discussion to general statements regarding the effect of a particular policy lever on the PSM process, the accessibility of the model's algorithms allowed discussion to further explore why and how changes occur. In some cases, it was determined that the true causal link was not as initially intuited. For example, many felt that reducing the number of suppliers would improve responsiveness. But with further discussion, it became evident that responsiveness improves only when parts are ordered and/or delivered faster (or if more parts are in inventory). Contrary to conventional wisdom, which believed there was a variance in supplier performance that could be exploited, reducing the number of suppliers alone had little effect on the order and delivery times as all suppliers had similar performance with respect to order and delivery time requirements.[134] Reducing the number of suppliers, while useful in many respects, does not directly alter the responsiveness of the PSM process. Forcing technical experts to quantify how the policy levers interact with the PSM process helps ensure that these links are properly understood.

In the end, the relevance of any analysis is its ability to communicate to policy makers the important features of the analysis and why policy change of a particular form is desirable. This point was emphasized by Lt Col Douglas Humerick, Deputy Chief Purchasing and Supply Chain Management Integration Division, Oklahoma City ALC.

> [The PSM model] helps communicate [to leadership] why analyzing the current PSM system is a time consuming and complicated process and how changes can not be made individually. [It] depicts the inter-relationships and inter-dependencies that must be considered during analysis. Concurrent analysis of multiple nodes and relationships is required to yield the most reliable outcome.

Using a system dynamic model to analyze the PSM process not only quantifies the discussion of the process with experts and system participants, it has the ability to assist in transmitting how and why policy recommendations affect relevant performance measures to policy makers.

Model Limitations

No discussion of the development and applicability of a model would be complete without recognizing some of its limitations. The model developed for this dissertation is no exception. All models omit system details thought not to be critical to the primary objective of the model. If the model developer felt they were critical, they would have been included in the model's design. However, some of these details warrant mentioning as they restrict either the generalizablity of the findings or the efficiency of the model at recreating the system being modeled. Due to limitations in Analytica or system dynamic models in general, the following limitations or observations were noted during the development of this PSM model. Where applicable, the significance of these factors should be considered when evaluating both the results and the utility of the model for similar scenarios or uses.

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[134] The performance times were established prior to awarding a contract and most suppliers are able to adjust their production processes to meet these requirements. Without strong performance incentives, suppliers have little motivation to shorten these times. Top performing suppliers use this "extra" time to operate more efficiently thus improving their profit margins.

1. Model Assumptions may be idiosyncratic to the Air Force or to the F100. While many of the assumptions used when determining the effects of the various policy levers or developing the functional forms and parameters used to populate the model are generic in nature and apply to the sourcing of any goods or services, some assumptions may not apply to another data set. Where possible, those assumptions that are unique to the Air Force or the engine spares market have been noted, but additional changes may be needed if the model is used for other data sets. The extent of these changes is not fully known and will require addition research to determine how well the model can be used for other data sets.

2. All parts are considered equal. Without a detailed understanding of how the various parts interact within the F100, it is not possible to weight parts differently when evaluating the performance of the PSM process. In reality, some parts are critical to the operation of the end system (in this case an engine) while others are less important, and while they might limit the scope of operations, they do not necessarily render the engine inoperable. As discussed earlier, some parts can be cannibalized or "borrowed" from other engines awaiting parts to produce a working engine, but this cannibalization process is not possible for all parts. In the real world, specific information regarding the criticality of a particular part and the ability to "expedite" its procurement will result in minor variations in the performance of the PSM process that the model does not capture. While these minor variations are important during the short-term operation of the system, they do not alter the overall need to understand the long-term interaction of the PSM process and policies, which are captured in the current model design.

3. In the real world, some demands are known. When forecasting the demand for spare parts, some fluctuations in demand due to exercises and seasonal changes in flying rates can be incorporated into the forecast methodology. The model lacks the ability to adjust the accuracy of the forecast (the variance in the demand for a particular part or set of parts based on known events). While the model could be modified to incorporate information regarding the particular distribution of demands, this modification requires additional information regarding the nature of the demands that was not available for the existing data sets used to support this research effort.

4. Model is data intensive. As with all models, the quality of the output is directly proportional to the quality of the data input into the model. Representing all potential spare parts requirements for a system as complex as the F100 engine requires the sampling of many different sources of data. While this data requirement has been purposefully kept to a minimum, a significant

amount of data preparation was required (see Appendix B for details on the data preparation process). In addition to the resources required to perform this data collection and analysis, requiring significant amounts of input data limits the number of areas that can be studied to those areas for which sufficient data is available, or for which resources are provided to acquire the data.

5. Analytica is proprietary software: The true value of a model is not just the final results, but learning how the system actually operates during the building process.[135] This suggests that the model should be used by personnel in the field of PSM to better understand how the process works, improving the model and thereby improving the quality of its output. Unfortunately, Analytica is not widely used by the Air Force at this time, with a limited number of licensed copies owned. Few PSM personnel are currently trained in or are familiar with Analytica or system dynamic modeling in general, which limits their ability to adapt or expand the model. Consequently, the Air Force modeling personnel would need to assist in analyzing potential changes to PSM policy levers and reporting the results to the decision maker, which reduces the utility of the model.

6. Computing limitations remain. While modern computer systems are considerably faster and more capable than they were several years ago, computing limitations remain. Despite the model's relatively simple design, even this high level model requires time to operate. When modeling all 123 parts with only one setting for all PSM levers, the model requires 40 seconds to compute all outcome measures using a Windows based laptop computer with a 1 GHz processor. While generating alternative combinations in "real time" is possible, this slight delay makes performing the large-scale computational experiments needed for exploratory analysis a time consuming process.[136]

7. The model requires large amounts of computer memory. Related to the speed of the model is its need for large quantities of computer memory. This is largely an artifact of the Analytica software, which computes all possible permutations of each node and stores the results in memory. While this facilitates the building and manipulation of multiple dimensional arrays, it restricts the total number of permutations that can be computed at any one time (on a laptop with 512mb of RAM and 1.7Gb of system memory, about 30 different policy combinations can be computed at once).

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[135] Forrester Jay W., "The model versus a modeling process," *System Dynamics Review*, Volume 1, No 1, 1985, p. 133-134.

[136] With just three possible values for each of the eight policy levers there are 3^8, or 6,561 different permutations of these levers to calculate.

8. Analytica contains idiosyncratic language features. Like any software package, Analytica, contains features that make representing some system functions difficult.[137] While software limitations can be overcome with additional programming, it increases the complexity of the model and increases the computation time of each model run.

In summary, while the model developed in this dissertation is thought to provide a reasonable representation of the PSM process both within the Air Force and for other enterprises in general, the results of the model must be interpreted with caution and not implemented without understanding why they occur and under what conditions they apply. In the case of the F100 engine, the next chapter reviews the output from the model when each individual policy lever is adjusted to validate that the model performs as intended. Chapter 6 then presents some findings from the model and interprets these findings to develop a specific set of policy recommendations regarding potential changes to the PSM process and the anticipated benefits of implementing these changes.

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[137] Two items were particularly noteworthy in the building and execution of the PSM model. First, when building and executing "If ... Then ... Else ..." statements for multi-dimensional arrays, should the conditional value being evaluated contain at least one true and one false value, then both the Then and Else conditions are evaluated for all items in the array. For example, the statement "If X= 0 Then 0 Else 1/X", works if X is a single number, but if X is a list of numbers like {0,1,2} rather than evaluating each value independently and producing {0, 1, 0.5}, Analytica reports a division by zero error. This produces computational errors that prevent the use of such statements in several cases such as when computing the receipt of parts that have varying lead times.

The second limiting aspect of Analytica is the difficulty the model had in computing random demands from a Poisson distribution for an array of parts over time. While the Poisson function worked reliably when used with a single input value (i.e. 4 demands/month), it often reported an error when given an array of input values. The root cause of this error was never ascertained, but was avoided by using a fixed table of demands (generated individually) for a majority of the analysis and only generating random demands to test the robustness of the final recommendations to different demand streams.

5. Individual PSM Policy Lever Effects

The second objective of this dissertation was to determine if a system dynamic model and the process of exploratory analysis would be useful in understanding how PSM policy levers interact within the PSM process, and if this exploratory analysis could not only improve the understanding of the process but support the development of useful policy recommendations. With the model completed and populated with a data set representing a subset of the parts purchased to support the F100 engine, an analysis can be performed with the model which can be analyzed and validated against expected results of modifying the individual policy levers based on economic theory and expert opinion that are described in detail in Appendix C. However, before exploring the interaction of the policy levers, each policy lever is varied individually to determine its effect on the PSM process and the performance measures of interest.

This chapter examines the effect of varying individual policy levers. First, the range of values possible, when varying individual policy levers, on each individual outcome measure must be determined. Once the range of outcomes is understood, the effect of each individual policy lever on all outcome measures is explored to understand how each lever affects the outcome measures. Once the model has been validated to produce understandable results in the one-dimensional cases, Chapter 6 explores simultaneous changes to multiple policy levers.

Base Case

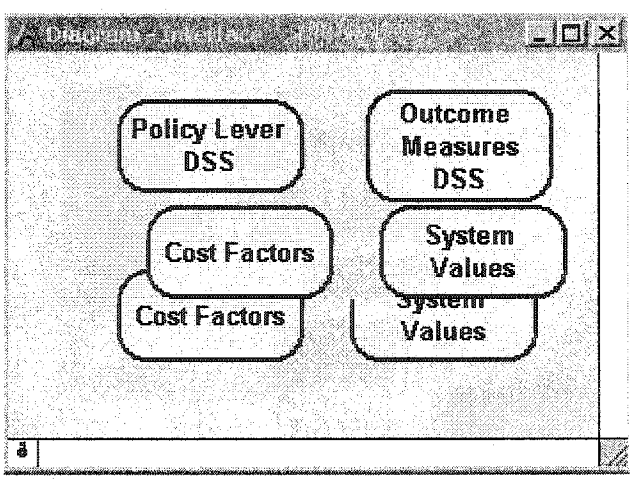
With the model established and populated with a sample of parts from the F100 engine, the base line performance of the model can be presented. This presentation accomplishes two objectives. First, it describes those features of the model that can be used to calibrate the PSM model to the dataset used in the analysis. Additionally, the results of the model as it represents the current PSM practices supporting the F100 engine are presented and discussed. This base case is used as a point of reference in later analysis of alternative policy lever configurations.

In the future when the model is used with other databases, additional calibration factors may be added as other areas of the model are identified that must be adjusted to allow the model to accurately reflect the performance of the PSM process used to support these datasets. However, at a minimum these factors should be reviewed and adjusted as needed to ensure the model properly captures any unique features in the dataset used.

The results of the base case are then presented to ensure the model not only functions as desired. This includes a description of the format used when presenting the results of other policy configurations later in the dissertation. Finally, this baseline case will be analyzed to ensure it captures the PSM process used at Oklahoma ALC, and to identify any limitations or unique features of this process that may limit the generalizability of these findings to other databases. This lack of generalizability will limit the ability of the model to produce results that can be used to develop policy recommendations regarding the configuration of the policy levers to improve the performance of the PSM process for both the F100 engine as well as other sets of goods and services.

To operate the model, a separate interface module was created that captures all of the various configuration parameters as well as nodes for all model inputs and outputs (Figure 18). Each of these for sub-modules will be presented with the values assigned in the base case to show how the model can be tailored to different databases and decision maker preferences as well as to demonstrate how different configurations of the policy levers are input and how the results of the model are combined into higher level measures of cost and performance.

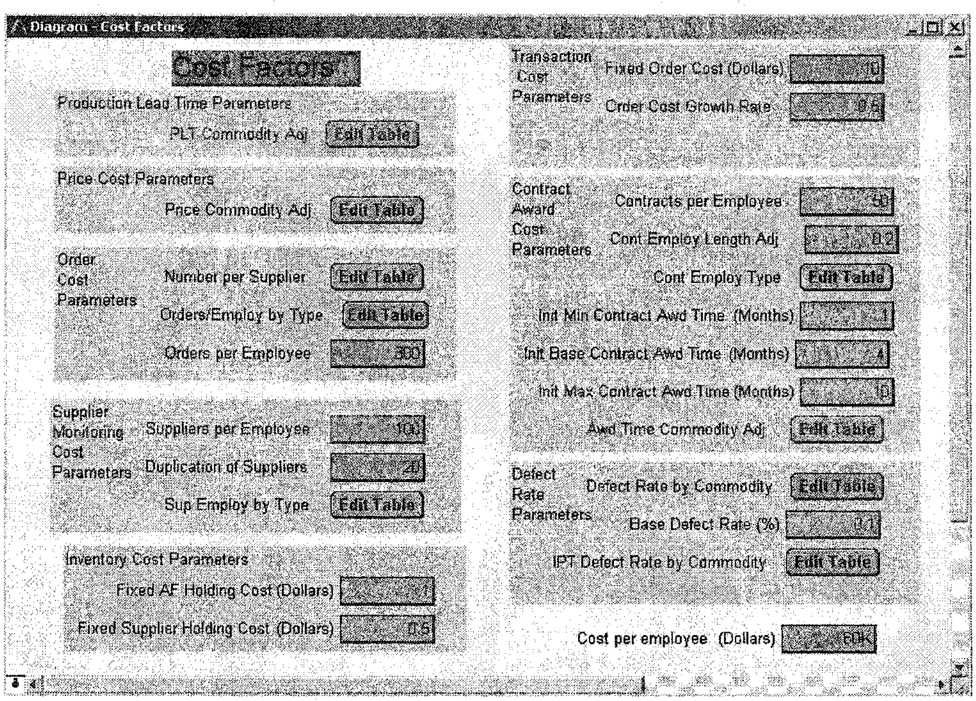
Figure 18: PSM Model's Interface Module



Model Calibration

With the model designed and the dataset of F100 parts input into the models's data tables, one additional step is required prior to calculating the results for each of the outcome measures in the baseline case. As many of the parameters of the model depend on the nature of the parts being modeled and the costs associated with operating the PSM process with existing personnel, these unique features are captured in the cost factor sub-module of the model's interface module (Figure 19).

Figure 19: PSM Model Cost Factors Sub-Module



The first several nodes of this figure represent tables of numbers that vary by commodity group, contract type, or other dimension that prevents the value of these factors from being displayed as a specific number. Within the actual model, these tables can be opened and the individual values adjusted as needed. The first numerical value of orders per employee represents the number of orders an average employee can process in a year. In the base case this value is assumed to be 100 indicating that 100 orders can be proceed in an employee-year or about one every 20 hours of employee time (2080 hours in a standard year divided by 100 orders/employee). Similarly, the suppliers per employee field represents the average number of suppliers monitored by one employee. The duplication of suppliers field assumes that the average supplier provides 20 different parts, limiting the extent that the number of contracts per supplier can be consolidated.

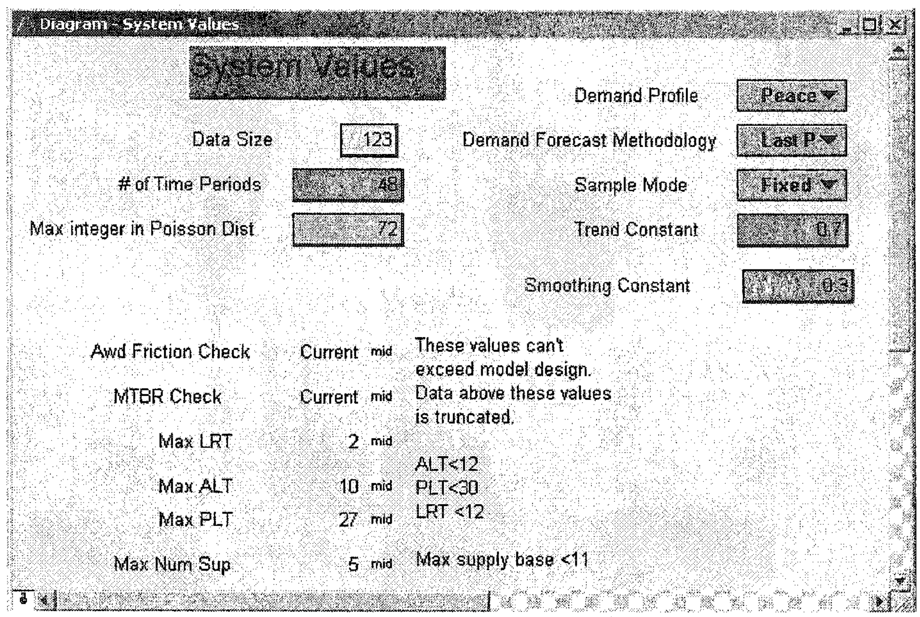
Under the category of inventory cost parameters are two nodes representing the fixed costs of holding an average part each month within Air Force inventory and at the supplier. Suppliers costs are lower as it is assumed they do not have to hold the entire asset, just the time critical components.

The right had column begins with the fixed costs per order of $10, and the growth rate representing the rate at which the cost of processing the order grows with respect to the dollar value of the order. This parameter reflects the increased cost of processing an order when the cost of the order doubles (assuming a logarithmic rate of increase). The contracts per employee node assumes that each employee can award on average 50 contracts each year or one every 40 hours of effort. The contract employee length adjustment field contains the number of additional employees required for each additional year of the contract length, assuming longer contracts require more time at an exponentially decreasing rate. The following three fields reflect the distribution of contract award times, which in the base case assumes a median contract award time of 4 months and a minimum and maximum time of 1 and 10 months, respectively. In the defect rate parameters section of the cost factors sub-module, there are two tables of data containing the average defect rate for each type of commodity and the adjustment factor to be used for each commodity when in the level of IPT use is increased. This table also contains the base defect rate, which for F100 engine data is assumed be 0.1%. This implies that 1 part in every 1000 received have some type of defect (defects are defined as any deviation from contract specifications, many of which are minor in nature and do not affect the functionality of the part or can be easily repaired by the Air Force). The final data field in the cost factors sub-module is the average cost per employee used to compute the dollar cost of all personnel activities.

Adjusting the values contained in the cost factors sub-module of the model, enables the model to accurately capture the nature of the PSM process for the current item list. By explicitly capturing these parameters in one portion of the model, it separates those portions of the PSM process that are generic to all items from those values that change when analyzing different lists of specific goods or services.

Similar to the cost factors sub-module, the system values sub-module contains nodes that allow the model user alter how the PSM process is modeled (Figure 20). The settings in this sub-module control the operation of the model to include how the model generates failures, and some diagnostic nodes in place to ensure that the model is able to handle the range of values present in the database under analysis.

Figure 20: System Values Sub-Module



The system values sub-module begins with a node allowing the operator to limit the analysis to a sub-set of the data loaded. As indicated in Figure 20, the in the base case (as with all model runs discussed in this dissertation) uses all 123 parts included in the F100 sample data input into the model. The number of time periods can also be adjusted allowing the model to extend operations further into the future if desired. In this analysis, 48 months of data were computed.[138] The right hand column of this sub-module contains nodes to select the demand profile used in the model. Alternative demand profiles are discussed in more detail in Chapter 6 when analyzing the robustness of the recommended configuration. The demand forecast methodology allows the user to select different methods of forecasting demands to include using the last period, a moving average, or an exponential smoothing forecast methodology,[139] as well as the use of a fixed demand table or a randomly generated table of demands. When using the exponential smoothing methodology, the trend and smoothing constants can also be set by the user. Finally, this sub-module has several nodes that allow the user to determine the extreme values present in many of the

[138] The model considers the first 12 months as a start-up period in which the model stabilizes with the settings selected for each policy lever. The values for each objective function are excluded for this period in calculating the averages reported in the output modules of the model.

[139] In this analysis, the last period forecasting methodology was used.

model's datasets. These values can be used to ensure the data has been input correctly or to ensure that the range of these parameters does not exceed the limits for which the model was designed to accommodate. A text node is used to inform the user of the maximum values allowed for each of these check values. As seen in Figure 20, the F100 data set is within the designed limits of the PSM model.

Results from the Base Case

The initial point of comparison for all policy lever configurations is the base case shown in Table D. With all policy levers at their initial settings reflecting the Air Force's current practices, this base case assumes that the PSM process is unchanged. Included in this table are two sets of data, the scores for each outcome measure based on the current policy lever configuration, and the actual policy lever settings used to produce these levels of performance.

The first section of the table reports the actual scores for each outcome measure. In the case of performance measures (responsiveness, adaptability and quality), these scores represent the composite weighting of multiple sub-measures and by themselves have no unit of measure. The weights used to combine the individual metrics into higher level measures are set by the decision maker through the use of the outcome measures decision support system sub-module discussed later in this chapter. The ordinal values used in each outcome measure capture changes in performance with lower scores representing better performance. Although they cannot be meaningfully compared to each other, scores for other policy configurations can be compared to this base case to understand the direction and scale of improvement indicated for each performance measure. This use of ordinal scales with no unit of measure has the added benefit of focusing attention on the trends interrelationships between the measures rather than focusing on the precise numerical results.

For cost measures (price, inventory cost, transaction costs, and personnel costs), these scores represent a percentage change from a base case in which all policy levers are unchanged. While in theory these values should all equal one in the base case, most vary slightly due to random variations in demand patterns over time, or changes in the performance over the life of a contract that differ from the "average" case. For example, a part's price is assumed to decrease over the life of a contract, and in the current base case, due to randomly assigned contract lengths, contracts are slightly longer than average resulting in a base case with prices 0.9% lower than the true average price. As with measures of performance, for cost measures lower numbers indicate lower costs.

The second portion of the table presents the policy lever settings used to generate these results. These values represent the degree to which each policy lever is present with 1 being the base case and a value of 2 indicating a doubling (or 200%) of the extent a policy lever is utilized. The exception to this is the lever for inventory levels, which reflects the percentage of excess inventory held as a safety stock. The base line setting for each of these policy levers is shown in Figure 21.

Table D: Base Case Performance

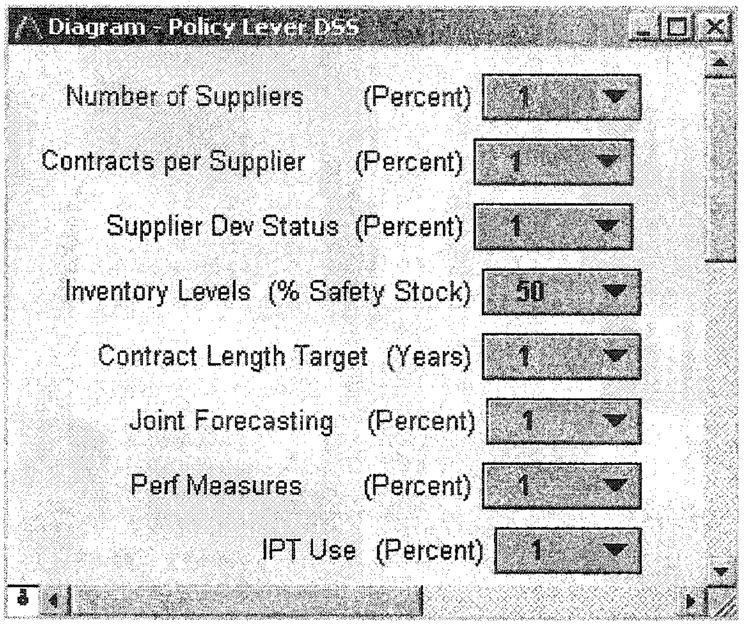
Output Measures

	Responsiveness	Adaptability	Quality	Price	Inventory Costs	Transaction Costs	Personnel Costs
Base Case	0.13	0.82	1.86	0.99	0.96	0.92	0.93

Policy Levers

	Number of Suppliers	Contracts Per Supplier	Supplier Development	Inventory Levels	Contract Length	Joint Forecasting	Performance Measures	IPT Use
Policy Lever Setting	1	1	1	50	1	1	1	1

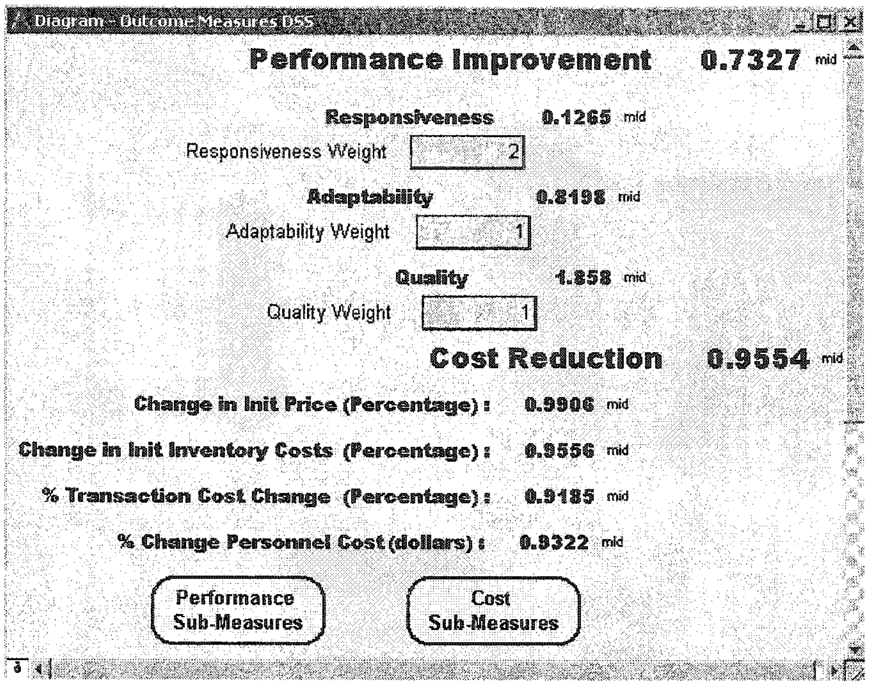
Figure 21: Policy Lever Sub-Module



Model's Interface or Decision Support System

The final aspect of the model that must be calibrated is the priorities of the decision maker regarding the relative importance of the various outcome measures. These weights are captured in the output measures DSS sub-module of the model's interface module (Figure 22). When producing the composite performance measure, the outcome measure of responsiveness is weighted twice as heavily as adaptability or quality to reflect the importance the Air Force places on providing parts to the customer when needed. As all cost measures are tracked in actual dollars as well as a percentage change from the base case, no weights are needed to generate the composite measure of cost.

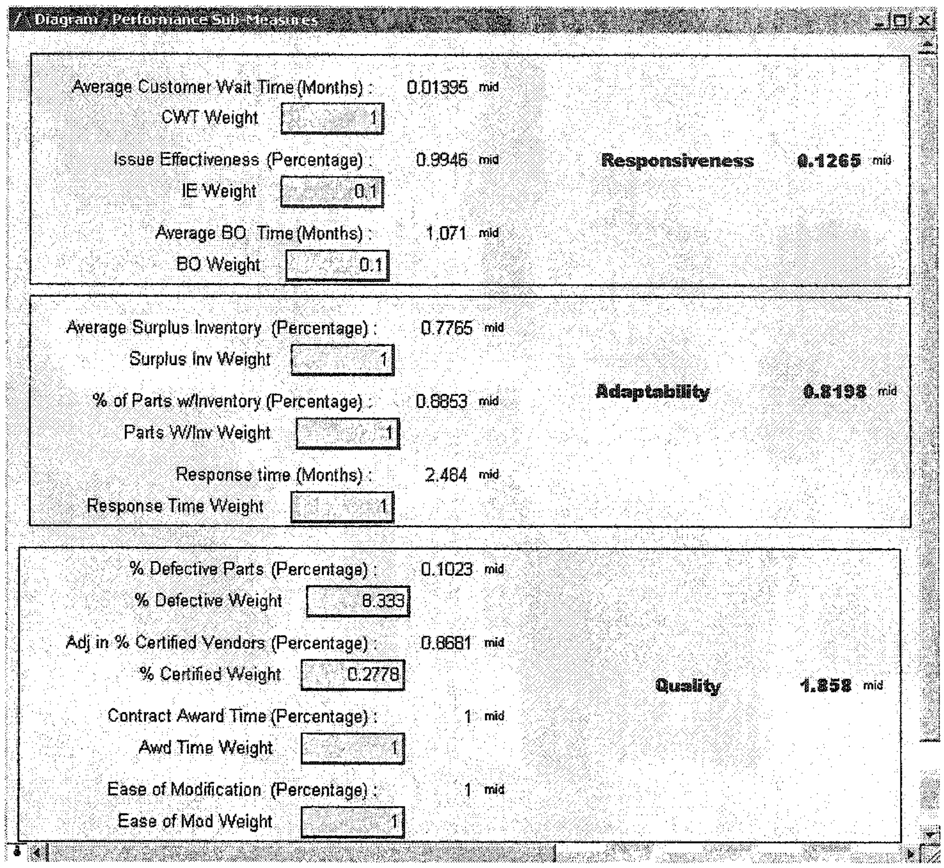
Figure 22: Outcome Measures DSS Sub-Module



As seen in Figure 22, this sub-module also contains two additional sub-modules used to combine individual metrics tracked by the model into the performance and cost outcome measures.

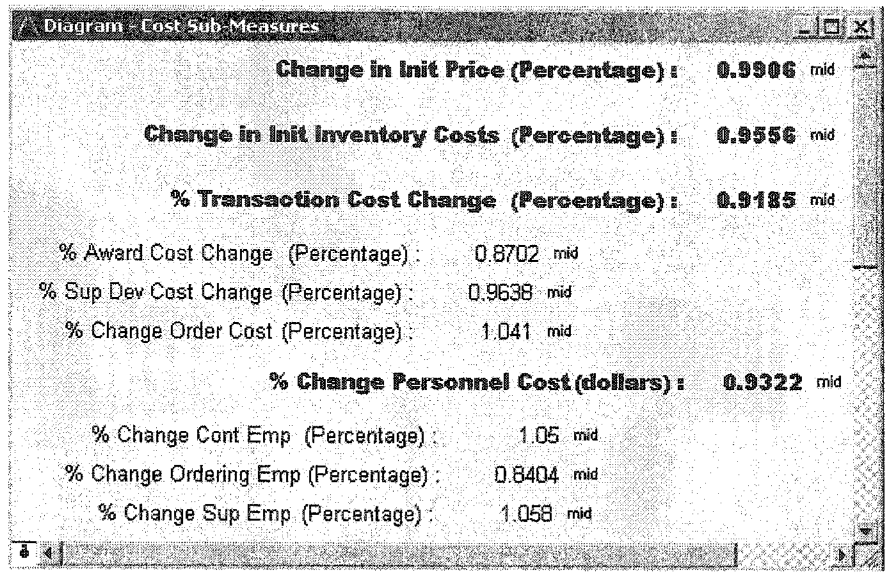
The weights used in the baseline case for to generate the performance outcome measures of responsiveness, adaptability, and quality are shown in Figure 23. To reflect the importance of customer wait time to Air Force decision makers this metric was weighted 10 times heavier than the other responsiveness measures of issue effectiveness and average backorder time. Similarly, within the outcome measure of quality, the percentage of parts with defects was heavily weighted to reflect the importance of ensuring engine parts are of high quality, while the percentage of certified vendors was given a relatively light weight as due to the criticality of engine parts, most engine suppliers must be certified to even produce engine parts. In the outcome measure of adaptability, all metrics were weighted equally.

Figure 23: Performance Outcome Measure Weights Sub-module



While the individual cost outcome measures are not weighted, each are composed of multiple metrics that are combined into the cost measures of price, inventory holding costs, transaction costs, and personnel costs. Figure 24 shows each of the metrics tracked to produce the cost outcome measures. As noted earlier, when these individual metrics are combined the actual dollars projected in each metric are added, but the outcome measures sub-module presents these metrics as a percentage change from the base case to ensure attention is not placed on the value of each outcome measure but the relative change in the size of the measure from current practices.

Figure 24: Cost Outcome Measure Weights Sub-module



Does the model capture the process at Oklahoma City ALC?

While one of the objectives of this dissertation is to develop a generic model of the PSM process to define the process and promote discussion, a second objective is to develop specific policy recommendations for improving the PSM process with respect to the F100 engine. The results of the model should parallel those of the physical demonstration conducted at the Oklahoma City ALC. If the model fails to capture critical features of the F100 PSM process, its results must be received with skepticism. To confirm that the model captures the salient features of the PSM process as it relates to the purchase of F100 replacement parts, the model was presented to eight members of the F100 PSM Integration Division. With few exceptions,[140] all personnel interviewed identified as critical aspects of the PSM process features that were already captured in the model. Those areas unique to the F100 engine or features of Air

[140] The one feature mentioned, but not captured in the model was the ability to shift risk between the buyer and supplier and how the distribution of risk affects the price paid for parts. Foe example, suppliers may attempt to provide a faster average production lead time, if they are compensated sufficiently to cover additional costs of accelerating production and the potential for not meeting this accelerate schedule (to include any penalties for failure). Additionally, in many cases it is possible to trade-off between cost, quality, or delivery time. For example, in many cases it is possible to accelerate production using additional shifts, or more expensive but faster production methods (using more but less efficient labor). This ability to trade between the various data elements, while significant in the short-run execution of the PSM process to minimize backorder times for critical parts is not captured in the model.

Force procurement in general that may not be fully captured in the PSM model are as follows:

1. Supplier risk. The profit margin for a given part (hence the price charged) corresponds directly to the amount of risk associated with its design, production, and sale. The production of low risk items for which there is a stable market (like steel) results in relatively small profit margins, while items for which production costs and market prices are uncertain have a much higher expected margin of profit (i.e. parts containing titanium whose price varies significantly). On a smaller scale, this concept of risk or uncertainty affects the price the Air Force must pay suppliers for engine parts. Parts for which the demand is uncertain, or if the Air Force asks the supplier to deliver the parts faster than the normal delivery schedule (either based on historical delivery times or the times parts are delivered to other customers such as commercial airlines) places increased amounts of risk on a suppliers ability to operate as planned. This increased risk is accompanied by higher prices. However, quantifying the level of risk and hence the price sensitivity of a particular transaction is difficult. The PSM model incorporates some of this risk by raising prices when more is expected of the supplier (i.e. participation in joint forecasting efforts), but the model lacks the ability to make the explicit trade offs between price and delivery time that are made in the real world to meet increased requirements or to recover from excessive quantities of backorders. Because the model is focused on the long run efficiency of the PSM process, these short-term trade-offs need not be included to develop good policy recommendations regarding the general structure of the PSM process. This limitation highlights the difference between a policy model such as the one developed in this dissertation, and models intended to assist in short term tactical decisions of how and from whom to purchase a given part or set of parts needed to support current operations.

2. Predominance of sole source parts. Unlike many commodity groups, a large percentage of the parts in the jet engine market have only one source (in the sample data 59 percent of the parts are sole source). Having a data set composed mostly of sole source parts limits the model's sensitivity to reductions in number of suppliers. Thus, while the model performs correctly with such a data set, the true effect of this policy lever in other data sets may not be reflected in the results of this analysis.

3. Importance of qualified sources. As engine parts are highly critical, particularly in a single engine aircraft such as the F-16, which uses the F100 engine, significant effort is devoted to avoiding defective parts regardless of the PSM process in place. Unlike most non-mission critical parts, suppliers of many

engine parts must first be qualified as a valid source of that part. This qualification process examines their production process as well as confirms that the supplier has the proper design and production specifications to ensure that replacement parts mirror the original items in all respects. This qualification is in many ways a more stringent quality control than traditional quality certification processes (such as ISO 9000 certification). Thus, with little variation in quality tolerated, changing PSM levers will have little impact on measures of quality reducing the ability of this objective measure to reflect the true difference between alternative policy configurations. When analyzing model results using the F100 data and formulating policy recommendations, variations in quality, as reported by the model, should be discounted with respect to other performance measures such as responsiveness or adaptability.

Range of Outcome Measures

Before exploring the effect of varying combinations of policy levers, the effect of changing each individual lever is analyzed. The scope of these changes on each outcome measure is presented and briefly discussed to understand the relative scope of change present when policy levers are adjusted. This incremental set of changes examines the cause-and-effect relations of each individual policy lever. In addition to building an understanding of the behavior of the system, these cases establish one step in the validation of the model.

This analysis serves three purposes. First, as a form of verification, it confirms that the model performs as expected. By comparing the results of changing each policy lever with the intuitive effects of such a change, the model can be tested to see if it produces the intended effects and relatively accurately represents how the PSM process would respond to changes in the policy levers. Secondly, while verifying that the model produces expected results, these results are compared to the economic theory suggested in Appendix C for each policy lever to validate that the results of the model are consistent with the theoretical effects of altering each policy lever. Finally, where the model's results vary from what was anticipated, further analysis is done to determine if these variances are due to unanticipated associations that exist or are lacking in the PSM process, or if these are an artifact of the model that must be discounted when developing policy recommendations based upon the model's results.

Each outcome measure is graphed with three different settings for each policy lever based on the ranges discussed in the previous chapter. As presented numerically in Table E, the initial value represents the minimum amount of a particular effort. For some policy levers, such as the number of suppliers, this represents the base case as the model assumes that based on the current practices of the Air Force to consider all possible suppliers, adding suppliers is not possible. In other cases, such as the use of performance measures, reductions to be baseline case have been considered and the baseline case is used as the medium value in the range for these levers. The medium level represents an increase in the application of the particular policy lever to either the baseline case or an intermediate position. The rightmost setting for each policy lever represents the most significant change deemed realistically achievable. The transition from "low" to "high" refers to the extent, not direction, in which the policy lever is altered, and in the case of contracts per supplier, where fewer contracts are present in the high case, represents a reduction in the quantity of suppliers. Alternatively, in the case of levers such as joint forecasting, the "high" values represent an increase in the use of joint forecasting. A more detailed discussion of the range of possible settings for each individual policy lever can be found in Chapter 4.

Table E: Range of Policy Levers Presented for Each Objective Measure

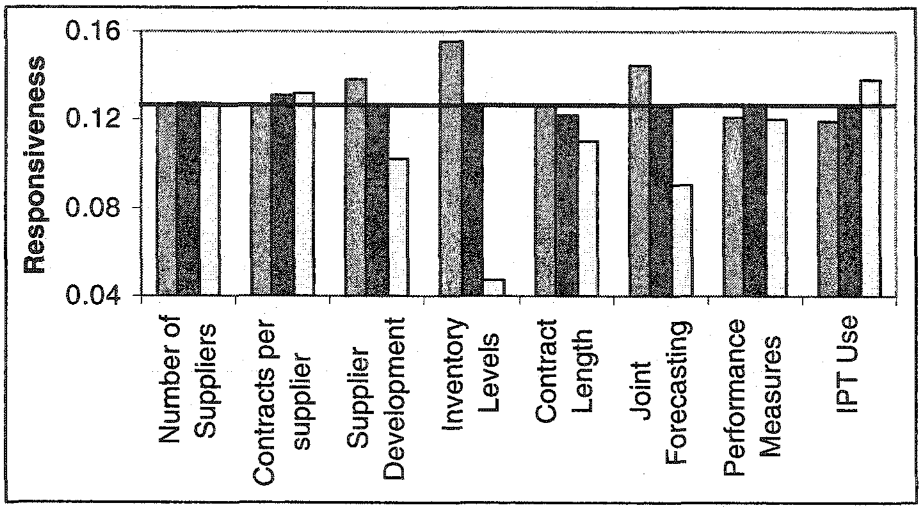
	Low	Medium	High
Number of Suppliers	1.00	0.50	0.20
Contracts Per Supplier	1.00	0.50	0.20
Supplier Development	0.75	1.00	3.00
Inventory Levels	10	50	100
Contract Length	1.00	1.50	3.00
Joint Forecasting	0.75	1.00	3.00
Performance Measures	0.75	1.00	3.00
IPT Use	0.75	1.00	3.00

Based on these changes to the individual policy levers, each outcome measure is examined individually to better understand the cause-and-effect relationships in the model. For each measure, three bars are displayed representing the "low", "medium", and "high" policy lever settings show in Table E. In the following section, as well as all displays of outcome measures in this dissertation, lower values are preferred representing improvements in cost or performance. To aid in determining the direction of change for a particular column, the baseline value of each outcome measures is presented as a horizontal line.

Responsiveness

As can be seen in Figure 25, the effect of an individual policy lever on the measures of responsiveness varies from only minor changes with variation in the number of suppliers, to significant changes with changes in inventory levels.

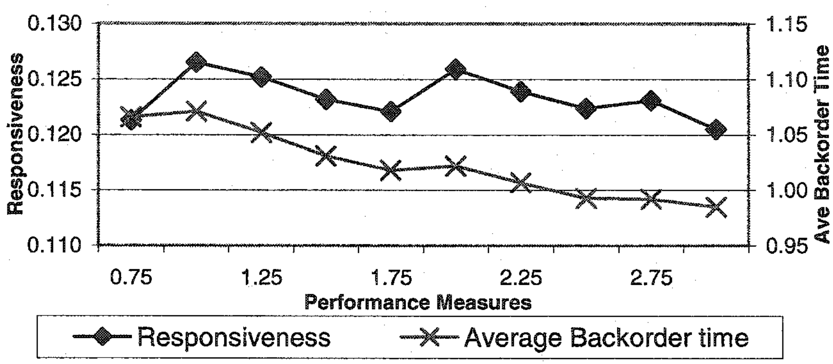
Figure 25: Responsiveness Outcome Measure



With responsiveness being driven by the ability to provide parts when needed to the final customer, levers that increase part availability such as increase in inventory or the use of supplier development and joint forecasting would be expected to improve responsiveness. Alternatively, levers that work to improve the efficiency of the process and don't significantly alter the quantity or speed in which parts can be sourced from suppliers, such as reductions in the number of contracts per supplier or the number of suppliers have minimal effect on this measure.

The effect of increased levels of performance measures has a non-linear effect on responsiveness as modeled. As shown in Figure 26, in general, increases in the use of performance measures improve responsiveness by reducing the average backorder time. However, at various levels of performance measures (for example between values of 1.75 and 2.0), the model reduces responsiveness due to decreases in part availability. This decrease is caused by an artifact of the model involving a finite number of time periods. Larger contracts, which are more complex and therefore take longer to award result in larger contract delays; shifting the time when contracts are in place for each part. For some parts, the larger contract delays result in not having a contract in place at the end of the model run. The absence of a contract at the end of the model run for some parts, increases the total number of backorders and reduces responsiveness. This temporary reduction in responsiveness is not "real" but an artifact of a model that uses a finite number of parts and must end at a finite number of time periods, and in general responsiveness is improved with increased use of performance measures. Non-linearities, such as this change in responsiveness, show the importance of a robust exploratory analysis. An optimal solution around a particular point (i.e. performance measures of 2.0) may be a local optimum; with better overall results in another area of the response surface (performance measures of 3.0).

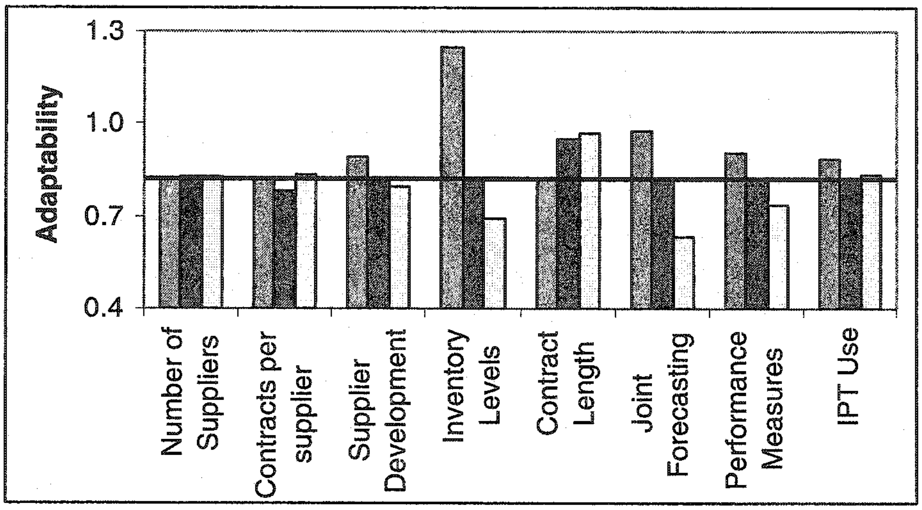
Figure 26: Performance Measures vs. Responsiveness Measures



Adaptability

Like responsiveness, the model predicts that the outcome measure of adaptability is most improved with increases in inventory levels as more parts in inventory directly improve the ability to respond to increases in demand (Figure 27). Thus, the increased use of supplier development and joint forecasting improve adaptability as does increasing the level of surplus inventory held as safety stock. Longer contracts, by increasing the difficulty of awarding and modifying these multi-year relationships increases the administrative lead time required to respond to increases in requirements, decreasing adaptability.

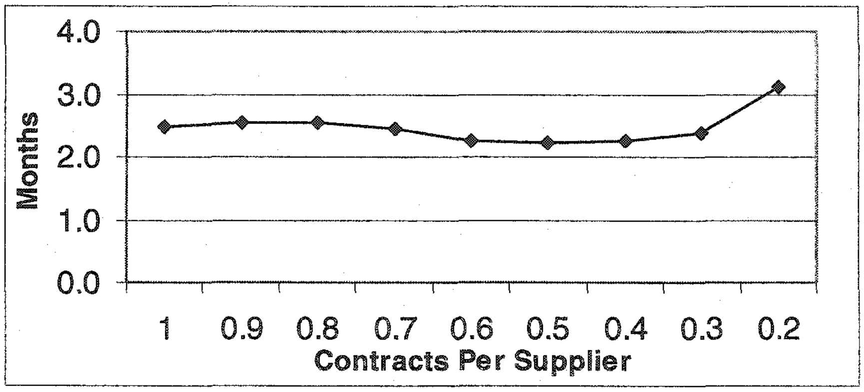
Figure 27: Adaptability Outcome Measure



The effect of decreasing the number of contracts per supplier on the performance measure of adaptability is more complicated. Fewer parts in inventory reduce the average number of parts with inventory and the average surplus of parts, but the effect of fewer contracts on response time is not consistent. As shown in Figure 28, initial reductions in the number of contracts per supplier slightly increase response times as parts without contracts must wait longer, due to increased administrative lead times associated with awarding larger contracts, for a new contract to be awarded.[141] However, further reductions in the number of contracts per supplier decrease response times. With longer contract award times, more parts are now delivered late, increasing the number of parts included in the computation of the average response time. As these "new" parts have a relatively short response time, the average recovery time (response time) is improved. Therefore, while the response time for a particular part is not improved with larger contracts, the performance measure appears to improve.

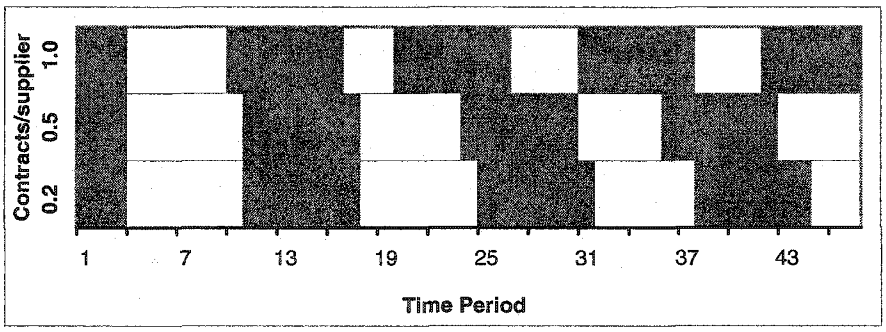
141 In the Air Force, contract award times are dependent on the number of reviews and the level of review needed to approve the contract. Larger, more expensive contracts have more in-depth review procedures that add to the contract award times. Unlike commercial enterprises, which can expedite the award of high dollar contract, the Federal Acquisition Regulations impose specific time constraints on how fast contracts of a certain dollar values can be awarded.

Figure 28: Response Time vs. Contracts per Supplier



When even fewer contracts are used (less than 50% of the initial number), it appears that response time is significantly worsened. However, this change is an artifact of a model involving a finite number of time periods. As seen in Figure 29, larger contracts, which are more complex and therefore take longer to award result in larger contract delays; shifting the time periods when contracts are in place for each part. For this particular part, the larger contract delays (periods in white) result in not having a contract in place at the end of the model run when the number of contracts per supplier is reduced. However, for the value of 0.2 a contract is in place two periods longer than with a value of 0.5 (a contract is in place until period 44 rather than expiring in period 42). The presence of a contract closer to the end of the model run allows more parts to be ordered from suppliers within the model's finite time period, appearing to improve response times. This improvement is not "real" but a refection that the model must end at a finite number of time periods.

Figure 29: Contract Availability for Sample Part



Without examining why response time is improved, Figure 28 would suggest that to improve response time would be to reduce the number of contracts per supplier. This improvement would not occur in the real world where time is transient and does not "end" after a given number of periods. Model artifacts such as this are rare and as they depend upon the unique combination of many factors do not alter the overall finding that performance, in general, is worsened with decreases in the number of contracts per supplier. However, this example highlights the importance of not simply implementing the results of a complex numerical analysis such as this model, but to first ensure the results are representative of real phenomena and are not just an artifact of the simulation.[142]

The increased use of IPTs, initially improves the performance measure of adaptability through improvements in the average response time. As discussed in Chapter 4, with decreases in the number of contracts per supplier, by assuming IPTs must work within the current Air Force structure longer contract award periods caused by increased IPT use actually increases the number of delinquent issues. Adding additional delinquent parts with a relatively short response time improves the average response time required to satisfy all deferred orders. IPT use that increases this improvement is offset by the lack of parts which reduces the other adaptability measures of the percentage of parts with inventory and the average part surplus, which both of which are negatively affected by an increased lack of contract availability.

Quality

The quality of the support provided by the PSM process varies with changes in all policy levers (see Figure 30). As they do not directly affect the quality of the parts sourced from suppliers nor the nature of the relationship with suppliers, joint forecasting and contract length have only a very slight effect while quality is improved significantly with increases in supplier development and IPT use. Increases in inventory levels, increase the average age of the parts in inventory resulting in additional damage and corrosion to these parts and increasing the percentage of defective parts.

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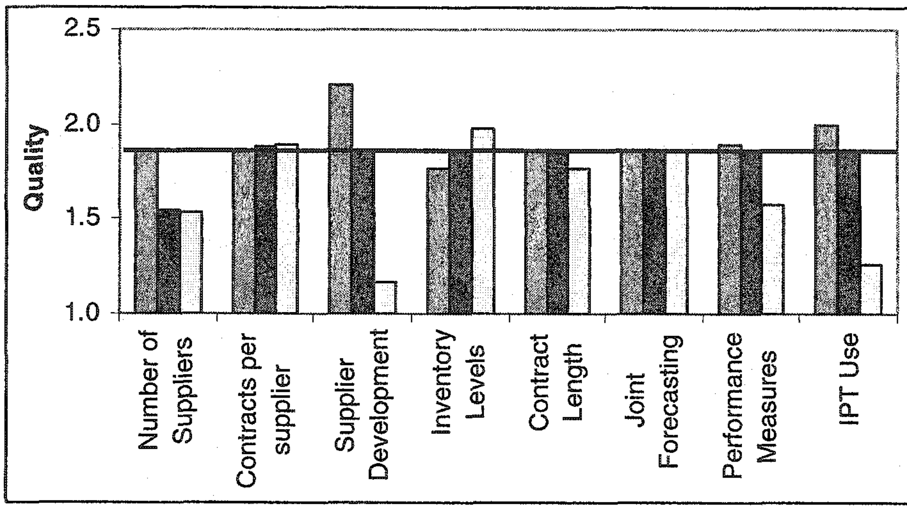
[142] This effect depends upon the shifting of the availability of a few key parts to all expire just before the end of the model's time period. With the use of random contract periods or additional changes other than the single policy lever of the number of contracts per supplier, this effect is eliminated and the model performs as anticipated.

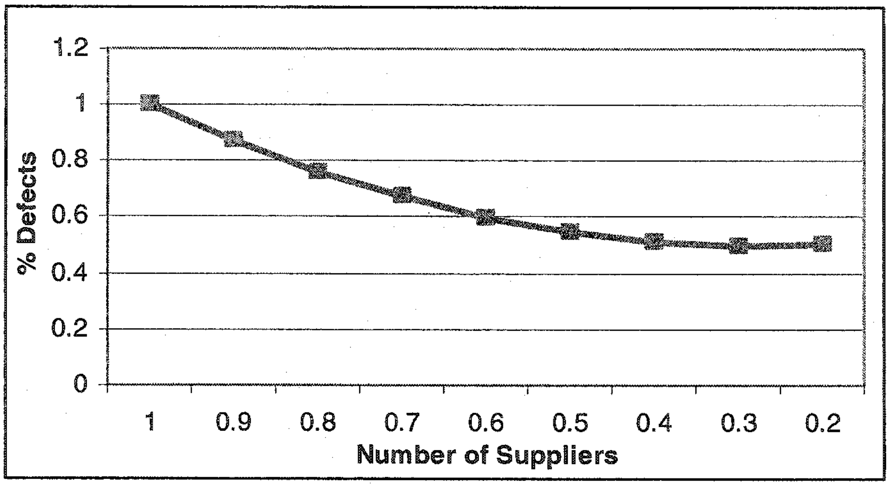
Figure 30: Quality Outcome Measure



Eliminating poor performing suppliers, reductions in the number of suppliers improve part quality. Similarly, performance measures and supplier development both reduce the number of defective parts and improve supplier quality by improving the performance of suppliers. It is worth noting that after the initial reduction in the number of suppliers which results in a significant quality improvement, further reductions have little effect, while the opposite is true for increases in the use of performance measures, initial increases have little effect, but the rate of quality improvement increases with the additional use of performance measures. This is a result of the functional forms chosen to model each of these policy levers effect on quality. According to the theory of diminishing returns, it is assumed that the initial increases in the use of the PSM policy levers will have the most effect with further increases adding incrementally smaller improvements to the outcome measures. For example, as seen in Figure 31, decreases in the number of suppliers reduces the number of suppliers at a decreasing rate. This relationship was modeled using quadratic as the functional form with parameters chosen to achieve the maximum reduction in the number of defects (a 30% reduction) with a 70% reduction in the number of suppliers. While the specific functional form and parameter values were derived from discussions with personnel from Oklahoma City ALC, in general they are consistent with both the economic theory of diminishing returns and the experiences of commercial companies.[143]

[143] Trent and Monczka find commercial companies have improved quality upwards of 10% per year. Trent, Robert J., and Robert M. Monczka, "Purchasing and Supply Management Trends and Changes Throughout the 1990s," *International Journal of Purchasing and Materials Management*, Fall 1998, pp. 3-4.

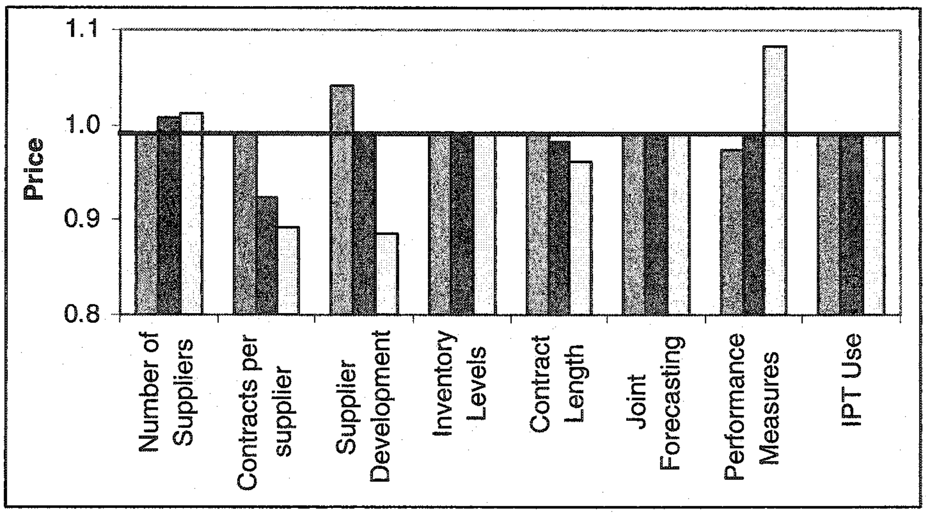
Figure 31: Number of Supplier's Impact on Percentage of Defects



Price

As the largest cost category, the effect of changes in purchase prices is particularly important (see Figure 32). However, as they do not alter the leverage with the supplier or the suppliers own production processes, three of the policy levers have no direct effect on the price of parts (inventory levels, joint forecasting, and IPT use). Decreasing the number of contracts per supplier increases the leverage the Air Force has with suppliers and with larger orders allows suppliers to take advantage of economies of scale to reduce their costs and the price paid by the Air Force. Similarly, increasing the use of supplier development improves the efficiency of suppliers significantly reducing price.

Figure 32: Price Outcome Measure



Price is one of the areas the model encourages with performance measures. However, in the current data set, increases in the price suppliers charge to assume the risk of not being able to meet performance targets overshadow price reductions attributable to the use of performance measures. This is due a combination of factors. The relatively short contract length in the basic data set (average contract length is 12.1 months) does not allow suppliers to fully incorporate changes to production methods. Additionally, as the F100 has been in production for over 30 years, most process improvements that can reduce the price of the parts have been incorporated, and the parts in the current data set are sourced with firm fixed price contracts that are less sensitive to price incentives. Finally, with a majority of the parts supporting the F100 being sole source parts, performance incentives have little affect on prices that are determined largely by using certified cost and pricing data.[144] Similarly, due the limited number of suppliers for most engine parts, further reductions in the number of suppliers result not in increased buyer leverage and economies of scale, but an increase in monopolistic pricing resulting, on average, in slightly higher prices.

Inventory Holding Costs

As expected, by directly altering the number and cost of parts held in inventory changes in inventory levels have the most significant effect on inventory costs (see Figure 33). Other policy levers affect inventory holding costs in two ways. Either by altering the number of parts in inventory through adjustments to production lead times (lower lead times result in a need to hold less inventory to cover production delays), or changing the price paid for parts (as more expensive parts cost more to replace when damaged while in inventory).

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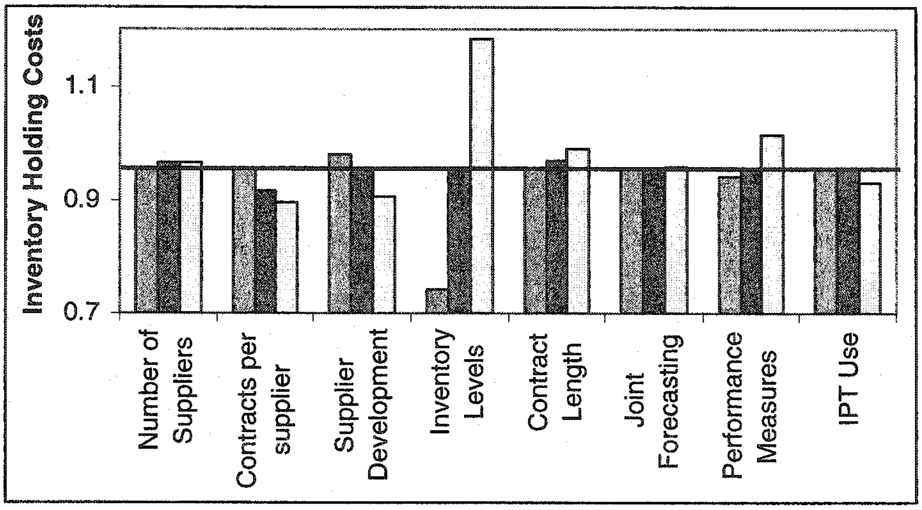
[144] Within a contract, prices are initially increased to offset the increased risk the supplier is assuming by using performance measures. As the contract matures, prices are reduced through incentives and the supplier's ability to improve their own internal practices. Prices fall with the use of performance measures only when a second policy lever is changed and very long contracts are used (an average contract length of 5 years or greater).

Figure 33: Inventory Holding Costs Outcome Measure



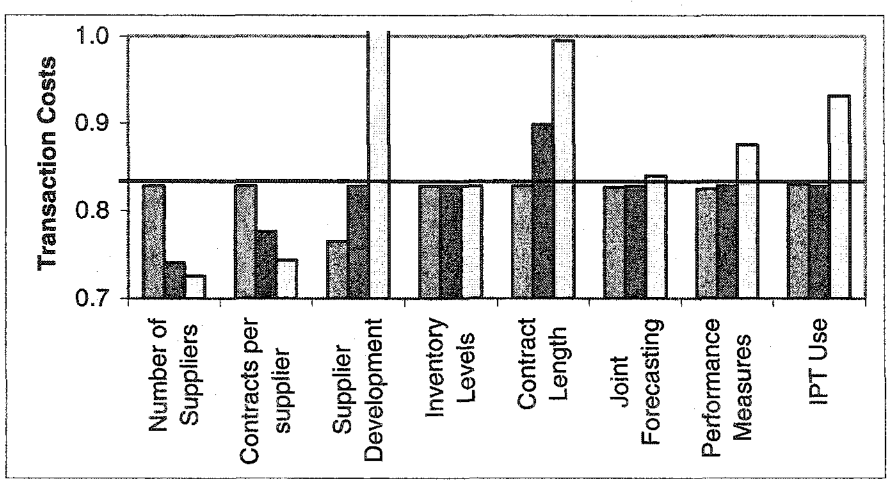
For example, as noted earlier with the current data set reducing the number of suppliers slightly increases the price of parts increasing the value of inventory damaged or broken during storage. Similarly, reducing the number of contracts per supplier improves the Air Force's leverage with suppliers and creates economies of scale that significantly decrease part costs and thereby reducing inventory holding costs.

Other policy levers such as the use of supplier development and performance measures reduce the production lead time of parts reducing the amount of inventory needed to be held to meet demands while suppliers manufacture new parts to replenish inventory levels. Fewer parts in inventory reduce the value of inventory as well as the amount of space required to store F100 engine spares. However, in the current data set the reductions in inventory levels associated with additional performance measures is offset by the corresponding increase in the price of parts charged by suppliers to assume the risk of not meeting performance measures. The effect of this policy lever on inventory holding costs may differ for other databases that contain parts whose price is more sensitive to the use of performance measures.

Transaction Costs

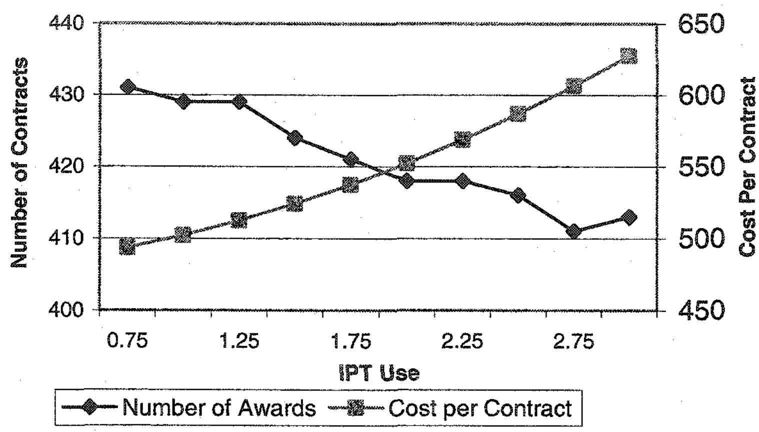
Because supplier development costs are a significant portion of transaction costs, this outcome measure is highly sensitive to changes in supplier development (see Figure 34). Compared to the cost of awarding contracts and cutting delivery orders, conducting extensive quantities of supplier development is relatively expensive (but still only a few percent of the cost of purchasing expensive items such as jet engine parts). Increasing supplier development costs to the highest level actually doubles transaction costs, but this bar was truncated to better show the variation in transaction costs due to changes in other policy levers. Decreasing the number of suppliers and the number of contracts per supplier decreases transaction costs, while inventory levels have no effect on this outcome measure. Alternatively, increasing the amount of joint forecasting and the use of performance measures add additional clauses to contracts and must be considered when awarding a delivery order, increasing the cost of these transactions and transaction costs in general. Similarly, longer contracts add additional option years that must be negotiated. As currently modeled, adding additional years to a contract increases contract award costs at an increasing rate as years farther into the future become more difficult to estimate and changes arising during the negotiation of these additional years may also necessitate revisions to existing contractual language. Thus, the coordination of increasingly large contracts becomes increasingly difficult, increasing transaction costs at an increasing rate.

Figure 34: Transaction Costs Outcome Measure



Initially, increases in IPT use decrease transaction costs as the added delay in awarding contracts results in fewer contracts to award. However, as IPT use continues to increase, the increasing cost of awarding individual contracts overwhelms the reduction in the quantity of contracts awarded, and the net result is an increase in total transaction costs. Unlike the earlier case where changes in the number of contracts per supplier resulted in non-linear changes that were an artifact of the model's finite time horizon, this non-linear effect is a result of the interaction of two separate changes, increases in the cost per contract and a decrease in the number of contracts awarded each year. These conflicting changes can be seen in Figure 35, which shows how increases in IPT use increase the cost per contract, while decreasing the number of contracts awarded. The minimum transaction cost is found with the current levels of IPT use.

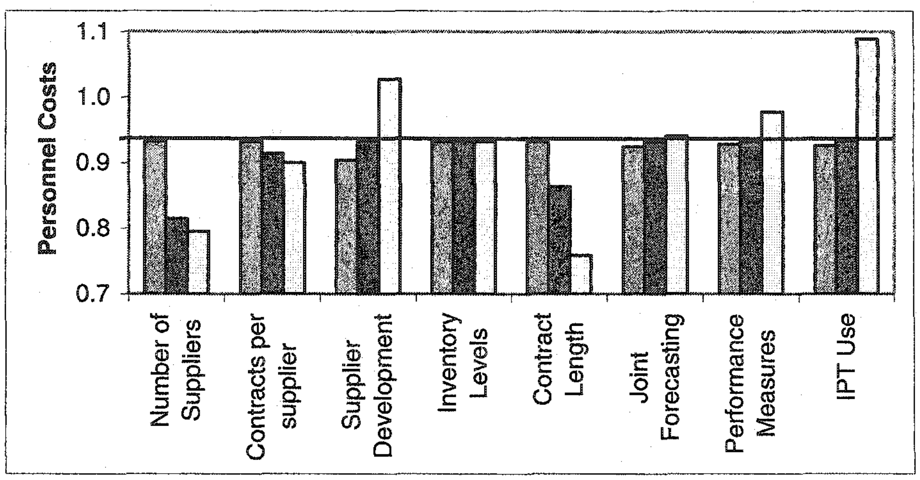
Figure 35: IPT Use vs. Contract Cost and Quantity



Personnel Costs

The final outcome measure of personnel costs is unaffected by changes in inventory level (see Figure 36). This outcome tracks the cost of Air Force personnel needed to oversee the execution of contracts and delivery order as well as to maintain oversight and contact with suppliers. By reducing the quantity of suppliers and contracts, respectively, the policy levers of number of suppliers and contracts per suppler reduce personnel costs as does increasing the average contract length. Conversely, by increasing the need for Air Force personnel to work with suppliers, the levers of supplier development and joint forecasting increase personnel costs. The use of performance measures, while not altering the number of contracts or suppliers, increases the complexity of these relationships resulting in an increased need for Air Force personnel to ensure they are managed and executed properly. Increases in the final policy lever of IPT use increases personnel costs as it is assumed that more people will be participating in the oversight of contracts, delivery orders, and suppliers. This increased participation, while improving the performance of the PSM process comes at the additional cost of increased Air Force participation increasing personnel costs.

Figure 36: Personnel Costs Outcome Measure



Now that the range of outcome measures is better understood, the effect of varying each individual policy lever is analyzed. By reviewing the effects of altering the individual policy levers from this perspective, the function of the model can be better understood, gaining additional insight regarding the effect of each policy lever.

Varying Individual Policy Levers

With the scope of changes possible for each outcome measure explored, this section summarizes those findings by policy lever to understand which levers in general improve costs and/or performance. This insight will be used in Chapter 6 to help select combinations of policy levers to further improve cost and performance and to identify combinations that may work synergistically to simultaneously improve both categories of outcome measures.

A summary of the effects of each lever on the outcome measures is presented in Table F). Cells in this table represent both the direction and magnitude of the change in each outcome measure when increasing the presence of each individual policy lever. Plus symbols indicate outcome measures that are improved by increasing the policy lever in question.[145] Alternatively, negatives represent consistent decreases in the particular outcome measure. Outcome measures not affected by a particular policy lever are represented with a zero.

[145] In this analysis lower values reflect improvement for all outcome measures. Thus, a plus sign indicates better performance either through lower costs, or reduced wait times improving measures such as responsiveness.

However, also represented in the figure are several relationships that are indeterminate in nature which are represented by question marks. In these instances, there are competing effects that make it impossible to state unequivocally if a incremental change to a particular policy lever alone will improve or reduce the performance in this outcome measure. The nature of these inconsistencies will be considered when discussing the effects of changing each individual policy lever below. The discussion that follows summarizes the results for each policy lever.

Table F: Effect of Changing Individual Policy Levers on Outcome Measures

Policy Levers \ Outcome Measures	Responsiveness	Adaptability	Quality	Price	Inventory Costs	Transaction Costs	Personnel Costs
Number of Suppliers	Slightly Worse	Slightly Worse	Large Improvement	Moderately Worse	Slightly Worse	Large Improvement	Large Improvement
Contracts per supplier	Slightly Worse	Unclear Effect	Slightly Worse	Large Improvement	Slight Improvement	Slight Improvement	Slight Improvement
Supplier Development	Large Improvement	Slight Improvement	Large Improvement	Large Improvement	Slight Improvement	Significantly Worse	Significantly Worse
Inventory Levels	Large Improvement	Large Improvement	Moderately Worse	No Effect	Significantly Worse	No Effect	No Effect
Contract Length	Slight Improvement	Moderately Worse	Slight Improvement	Slight Improvement	Moderately Worse	Significantly Worse	Large Improvement
Joint Forecasting	Large Improvement	Large Improvement	Slightly Worse	No Effect	Slightly Worse	Slightly Worse	Slightly Worse
Performance Measures	Unclear Effect	Slight Improvement	Large Improvement	Significantly Worse	Significantly Worse	Moderately Worse	Moderately Worse
IPT Use	Moderately Worse	Unclear Effect	Large Improvement	No Effect	Slight Improvement	Unclear Effect	Significantly Worse

Legend

+ (large)	Large Improvement	▬ (large)	Significantly Worse
+ (medium)	Medium Improvement	▬ (medium)	Moderately Worse
+ (small)	Slight Improvement	– (small)	Slightly Worse
O	No Effect	?	Unclear Effect

Number of Suppliers

In general, this policy lever has only minor effects on the performance of the PSM process as modeled. While reductions in the supply base enable other policy levers to be employed more efficiently, as a singular policy change adjustments do not result in significant changes to the performance of the PSM process. The sole exception is the significant increase in part quality as suppliers can be limited to those delivering the fewest defects.

As indicated in Table F, the overall performance measure of adaptability is slightly reduced with reductions in the number of suppliers. Traditional economic theory attributes this reduction to the fact that having fewer suppliers reduces the size of the supply base to the extent that the remaining suppliers are unable to meet "surges" in requirements.[146] As discussed in Appendix C, due to the uncertain nature of this association, the PSM model developed for this dissertation does not consider this a factor of reducing the supply base. Rather the reduction in adaptability is a reflection of the fact that reducing the number of suppliers increases the price paid for parts. This is true only for markets with limited competition, which is the case with may F100 parts. In competitive markets, decreasing the number of suppliers improves the leverage with those suppliers and results in lower prices. As parts that are more expensive require higher levels of management review and approval, this increased price slightly increases the average delay for awarding contracts. With a longer contract delay, the PSM process is less responsive and adaptive.

Decreasing the number of suppliers slightly increased prices with more sole source parts, resulting in increased inventory costs (as inventory holding costs are a function of both the quantity and price of the parts in storage), but decreases transaction and personnel costs as few buyer-supplier relationships must be maintained. The fact that reducing the supply base does not have a significant effect on the price of parts is partially due to the nature of the F100 supply base. With a large percentage of sole source parts, and only a limited number of suppliers for most parts (59% have only one supplier), reductions in the supply base are not possible. With a list of parts that are more competitive in nature, price reductions would occur as the Air Force could consolidate purchases with fewer suppliers, increasing buyer leverage.

Contracts Per Supplier

Overall, this policy lever reduces costs at the expense of performance. Reducing the number of contracts per supplier reduces the total cost of

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[146] Oklahoma City ALC personnel stressed that this capacity constraint was not a factor at the ALC in general and in particular with respect to engine parts. The industrial base supporting aircraft spares was sufficiently large due to the support of commercial airlines that changes in Air Force requirements could be met regardless of the number of suppliers the Air Force retained in the bidding pool.

administering contracts for all parts, and through increased leverage reduces the price paid for parts. However, with fewer large contracts, the average contract award time is increased and this increase results in longer gaps in contract coverage reducing responsiveness.[147] The quality of the parts received is not affected, but the contract support quality is reduced by increased time required to award contracts and the ease of making contract modifications. Fewer, less expensive parts reduce inventory holding costs as well.

Supplier Development

Working with suppliers, while increasing the cost of awarding contracts and conducting the development effort, improves all performance outcome measures. By improving the relationship with the suppliers as well as suppliers' own processes, production lead times are decreased reducing the need for inventory and improving responsiveness and adaptability. Improved supplier efficiency also decreases the average price paid for parts. The cost of conducting supplier development activities is captured both as a sub-category in the objective measures of transactions costs as well as an increase in the number of Air Force employees required to oversee suppliers which is part of the performance measure of personnel costs.

Inventory Levels

Increasing inventory levels has the anticipated effect of improving the measures of responsiveness and adaptability while decreasing part quality (parts sit on the shelves longer and are more apt to break or be damaged) and increasing inventory holding costs. As modeled, the tradeoff between improved performance and increased costs is linear in nature and does not suggest an optimal level of inventory. Finally, as setting a given inventory level results in no long-term change in the demand for parts or the contractual relationships with suppliers, the cost of sourcing the parts is not changed.

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[147] As discussed in Appendix A, when modeling contract availability it was assumed that all parts will have a small lapse in contract coverage. While in reality some parts always have a contract in place, identifying these parts is not possible with the data used in this model. The use of a smaller contract lapse for all parts reflects the fact that on average, some parts would be needed when a contract is not in place. The frequency of this occurrence and thus the size of this gap is dependant on the nature of the parts included in the model, and must be calibrated to each set of parts modeled.

Contract Length

The effect of increasing the average contract length on performance outcomes varies. While longer, more stable relationships improve quality, the increased difficulty of awarding and modifying these multi-year relationships increases the administrative lead time required to respond to increases in requirements, decreasing adaptability. Responsiveness is improved as longer contracts expire less often; ensuring parts have a source of supply a larger percentage of the time.

Where there is potentially more than one supplier for a part, longer contracts allow the relationship between the Air Force and a particular supplier to improve over a period of time reducing transaction costs, lead times, and motivating the suppliers to make internal improvement in their own processes. Knowing they will have time to reap a return on their investment, suppliers will undertake additional production process improvements resulting in lower overall prices. Reducing the value of inventory reduces the cost of replacing items damaged or broken while in storage, lowering inventory holding costs.

Joint Forecasting

The use of joint forecasting aids suppliers in preparing for future requirements thus improving the measures of responsiveness and adaptability. This improved performance comes at an increased cost to the Air Force to fund the supplier's participation (modeled as part of the transaction costs) as well as the increased effort associated with the Air Force participating in the joint forecasting efforts (increased personnel costs). As joint forecasting does not affect the Air Force's demand for parts, the number of parts ordered and the total purchase price remains unchanged. However, by improving production lead times, parts are received faster resulting in slightly higher inventory levels and thus a few more defects to slightly decrease overall quality.[148] These changes while real, are minor in scope and in the long run are insignificant from a policy perspective.

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[148] This inventory increase assumes that targeted inventory levels are not reduced to offset the improved performance of suppliers. In reality, if desired, with better joint forecasting the Air Force could reduce inventory levels and maintain performance at a reduced cost and improved quality.

Performance Measures

While any individual performance measure can be improved by adding contractual incentives for suppliers to improve that aspect of performance, when considering performance measures in general (used to a limited extent to improve quality, price, and delivery time) not all outcome measures are improved. In the current data set, adaptability and part quality are improved, but with the exception of a reduction in the average time to clear a backordered part, responsiveness measures are largely unchanged. Like increases in contract length, increased use of performance measures increases contract award time, producing non-linear changes in overall responsiveness due to variations in contract availability towards the end of the model's time period.

The cost of improving performance is captured in increased transaction costs as well as increased levels of contracting employees to monitor the execution of the performance measures. As alluded to earlier, price is one of the areas the model encourages with performance measures, but in the current data set incentivized reductions in price are offset by the increased price charged by suppliers to assume the risk of not meeting performance targets in other areas. This is due to the nature of the F100 engine which by being in production for over 30 years, allowing suppliers to implement most cost reduction initiatives in an effort to improve profit margins on the existing Firm Fixed Price contracts. For less mature parts, the effect of performance measures may need to be increased, resulting in lower prices with the use of performance measures. The increased purchase price also overshadows the reductions in inventory levels achieved by reducing production lead times, resulting in a net increase to inventory holding costs.

IPT Use

As discussed in Chapter 4, as modeled using IPTs increases the quality of the contracts by incorporating additional participants in the process, but this increased participation comes at a cost of increased personnel costs. Due to longer contract award and administrative lead times associated with increased IPT use, on average parts spend more time waiting contracting actions; reducing inventory and resulting in slightly lower responsiveness. Because the quantity of parts ordered and their cost remains unchanged, price is unaffected by changes in IPT use.[149]

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[149] IPT use is limited to improving the participation in current activities such as developing a contract, selecting suppliers, and monitoring supplier performance. The expansion of IPTs to include

IPT use has interesting effects on both transaction costs and adaptability. Initially increases in IPT use decrease transaction costs as the added delay in awarding contracts results in fewer contracts to award. However, as IPT use continues to increase, the increasing cost of awarding individual contracts overwhelms the reduction in the quantity of contracts awarded, and the net result is an increase in total transaction costs. Similar to transaction costs, the increased use of IPTs, initially improves the performance measure of Adaptability through improvements in the average response time. While these non-linearities are partially an artifact how the model parameterizes the effect of the PSM policy levers, they highlight the need to balance conflicting outcomes when selecting the preferred PSM policy lever configuration used to source a particular part or group of parts. This analysis also shows how, in many cases, the PSM model can identify unexpected associations between the components of the PSM process that result in unanticipated changes to outcome measures when making policy changes. These unintended consequences, once identified, can be considered when determining the future structure of the PSM process to support a given set of parts.

Validation

The set of cases presented in this chapter, permits the reflection of how well the model is capturing the significant aspects of the PSM process. The final important aspect of a modeling effort is to consider how well the model does in actually representing reality. When reviewing the effects of the individual PSM policy levers, the model largely produces results that are consistent with economic theory and assumptions underlying its design, as well as the data set used in it's execution. The model highlight the effects of the individual PSM policy levers, but it also highlights the effects of features unique to the F100 engine data such as a predominance of sole source parts, and the need for any PSM policy to account for those high cost items that drive much of the F100's spare part costs.

Are the general trends consistent with commercial literature? In a review of PSM trends throughout the 1990s, Trent and Monczka find commercial companies have improved quality upwards of 10% per year and most have

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the establishment of commodity councils or other strategic planning groups is beyond the scope of this model and the ability of proactive IPTs to improve the performance of the PSM process has not been incorporated into the current model.

achieved a 7-10% improvement in delivery responsiveness per year.[150] As the outcome measures used in this model are composites of a variety of measures over several years, computing an explicit percentage improvement per year is not possible, but overall the suggested improvements seem to be consistent with the size of improvements found in commercial experiences. Similarly, Patterson and Nelson report that one industrial equipment manufacturer's supplier development program reduced prices by 15%.[151] Overall, with the exception of the use of IPTs, which were modeled to fit within the Air Force's organizational structure, the findings of this study are in line with commercial examples indicating that the model's predicted improvement in the various outcome measures are not beyond actual historical examples.

So far, the calculations performed provide only one step in building confidence in the operation of the model. It was hoped that an ongoing test of F100 policies would provide empirical data to compare the model too. Unfortunately, during the development of this model, the F100 demonstration effort was disbanded, and PSM policy changes are now being developed and implemented AFMC wide. With the decrease in focus and management attention given to the F100 demonstration, this decision delayed the implementation of changes to the PSM process. Until empirical results are available, the validation of the model's ability to reflect changes made to the actual PSM process supporting the F100 engine is incomplete. Without the explicit focus of the demonstration, implementation of the PSM policy levers in support of the F100 engine will be an ongoing effort. Confirmation that the model's findings will be achieved in actual practice and will require further study and analysis comparing the model's results to the practices of the ALC over the upcoming months and years.

Now that the effect of each individual policy lever on the outcome measures is understood, to include a basic understanding of why individual changes occur, the interaction of the policy levers is considered to include how to best configure the policy levers to support the sourcing of spares for the F100 engine.

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150 Trent, Robert J., and Robert M. Monczka, "Purchasing and Supply Management Trends and Changes Throughout the 1990s," *International Journal of Purchasing and Materials Management*, Fall 1998, pp. 3-4.

151 Patterson, James L., and J. Douglas Nelson, "Executive Summary: OEM Cycle Time Reduction Through Supplier Development," *PRACTIX, Best Practices in Purchasing and Supply Chain Management*, Vol. 2, No. 3, March 1999.

6. Multi-dimensional Lever Configuration

With the model operating as designed, an in-depth exploratory analysis of how the PSM policy levers can be configured to improve overall performance and reduce costs can be conducted. This chapter examines the development of specific policy recommendations regarding the structure of the PSM process used to provide support for the F100 engine. The model is designed to determine the policy configurations that best improve performance and minimize total costs as two separate objectives. These competing objectives are then combined, balancing performance and cost in a recommended PSM policy lever configuration. This chapter concludes with a brief discussion regarding the validity of the model, or how well it is thought to represent the performance of a real world PSM process.

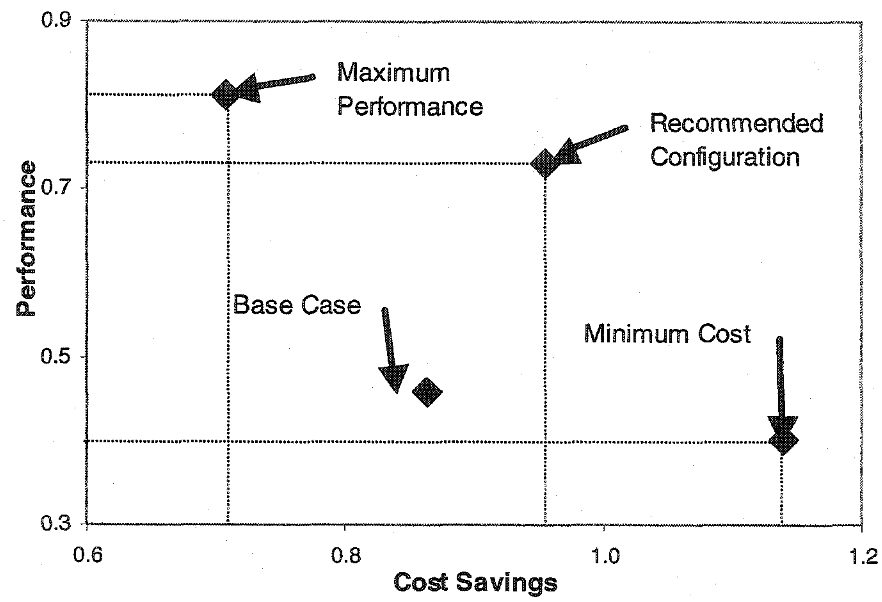
Policy Lever Interactions

While understanding how individual policy levers affect the PSM process is useful, the real benefit of an exploratory analysis is the ability to consider how the levers interact to exploit synergies and avoid undesirable interactions. The initial point of comparison for all policy lever configurations is the base case shown in Table D.

Recall that the base case presented in Chapter 5 represent the current PSM operations. Policy levers are scaled so that for the base case a scale value of 1 is used, except for inventory levels where a specific number is given. The policy levers are now adjusted in combination to improve cost and performance. While the number of policy lever combinations is infinite, limiting each policy lever to several values and exploring how those levers interact produces a variety of combinations that can improve cost, performance or both.

As shown in Figure 37, three policy configurations are discussed in this chapter. The first configures the policy levers to maximize performance regardless of the cost, while the second minimizes costs independent of performance. The final recommended configuration seeks to improve both performance and cost by choosing a configuration of the policy levers that improve both categories of objective measures. This incremental approach to finding the recommended configuration by exploring the range of performance and cost improvements, improves the understanding of how the policy levers interact and provides a range of possible cost and performance values to compare to the recommended configuration. As shown in Figure 37, by selecting the correct policy lever configurations, not only can the performance of the PSM process used to support the F100 engine be improved, but the cost of providing this support can be reduced simultaneously. These three configurations are discussed separately in the following section.

Figure 37: Alternative Performance and Cost Configurations[152]



Maximum Performance

To determine the set of policy levers that produce the best performance irrespective of the cost, the model was run with the best settings, with respect to performance, for each individual policy lever. As anticipated, this improved the composite performance score from 0.73 to 0.43, a significant improvement.[153] The model was then exercised with a variety of changes to individual policy levers as well as combinations of levers in an attempt to understand how

152 This chart is based on the concept of a productivity frontier developed by Michael Porter showing how cost and performance (value) tradeoffs are possible using best practices. Porter, Michael, E., "What is Strategy?" *Harvard Business Review*, November-December 1999, pp. 61-78.

153 The composite performance measure is a weighted average of all three performance measures with responsiveness being weighted twice as heavy as adaptability and quality. Responsiveness gets the extra weight as it contains the most critical Air Force measure of how long customers wait for parts. Adaptability and quality while important are of secondary concern to getting the parts required to restore end items to operation.

performance is improved and to determine if another configuration of the policy levers could result in additional performance improvements. As indicated in Table G, by reducing the use of IPTs and restoring contract lengths to their default value, performance is further improved to a composite value of 0.40.[154] This suggests that designing an "optimal" process is not achieved by simply optimizing each individual policy lever, but must consider the interaction of these levers.

Table G: Maximum Performance Configuration

Output Measures

	Responsiveness	Adaptability	Quality	Price	Inventory Costs	Transaction Costs	Personnel Costs
Base Case	0.13	0.82	1.86	0.99	0.96	0.92	0.93
Max Individual Policy Levers	0.04	0.58	1.06	0.93	1.14	1.73	1.03
Max Performance.	0.02	0.50	1.06	0.99	1.21	1.73	0.92

Policy Levers

	Number of Suppliers	Contracts Per Supplier	Supplier Development	Inventory Levels	Contract Length	Joint Forecasting	Performance Measures	IPT Use
Base Case	1	1	1	50	1	1	1	1
Max Individual Policy Levers	0.2	0.5	3	100	1	3	3	3
Max Performance	0.2	1	3	100	1	3	3	1

When adjusting individual policy levers, slight decreases in the number of contracts per supplier improved responsiveness by reducing the average response time, but when other policy levers are adjusted this slight improvement is offset by the increases in the number of backorders caused by the longer contract award times associated with larger contracts.

154 This result is partially a result of how the policy levers have been defined and the assumptions used to link the policy levers with the PSM model. For example, if a more proactive approach to IPTs had been used, increased IPT use may result in less frequent gaps in contract coverage, improving performance. As with many of the policy levers, the effect of a particular lever on the PSM process is dependant on the assumptions used to develop those links.

Similarly, as an individual policy lever, increased IPT lowered defect rates improving quality and overall performance. The presence of other policy levers such as performance measures and supplier development that improve defect rates, lessons the relative improvement from increased IPT use. Now, the increases in quality are not sufficient to overcome the reductions in other performance measures caused by the increased contract award times associated with increased use of IPTs. As modeled, these increases cause increased delays in meeting back ordered requirements, offsetting any quality improvements.

As expected when focusing solely on improving performance, this improvement in performance does not come without a cost. Overall cost increases 19%, with all cost categories rising with the exception of personnel costs. Reductions in the number of suppliers reduce the number of orders needed to source parts, which result in an 18% net reduction in the cost of ordering parts. With fewer orders to process, the number of personnel needed to process orders is decreased, lowering personnel costs.

Minimum Total Cost

To determine the set of policy levers that produce the lowest cost regardless of performance, the model was initially run with the best settings, with respect to cost, for each individual policy lever.[155] As anticipated, this reduced the projected cost operating the PSM process and acquiring the needed parts from 95% in the base case to 72% a significant improvement. A variety of changes to individual policy levers as well as combinations of levers were explored in an attempt to understand how cost is improved and to determine if another configuration of the policy levers could result in additional cost reductions. As indicated in Table H, by reducing the average contract length to 2 years and increasing supplier development by 50%, costs are further reduced to 71% of the "initial" value. It must be noted that this additional cost reduction came not at the expense of additional performance reductions, but surprisingly resulted in an improvement of the overall performance measure from 1.01 to 0.81. This is due to the increased contract availability associated with the longer contracts. Having contracts available a higher percentage of the time reduces the number of backordered parts, improves average customer wait time, and shortens the response time for those parts initially backordered. As with

[155] With all cost measures being reported in dollars, the total cost is found by adding the cost of each individual cost category. If dollars could be easily shifted between categories, this would be the only cost measure of interest. However, as government funding is appropriated in separate categories, the cost of these categories must be individually monitored.

determining the best policy configuration to maximize performance, achieving the lowest cost configuration is more complex than simply optimizing each individual policy lever, and must consider the interaction of these levers.

Table H: Minimum Cost Configuration

Output Measures

	Responsiveness	Adaptability	Quality	Price	Inventory Costs	Transaction Costs	Personnel Costs
Base Case	0.13	0.82	1.86	0.99	0.96	0.92	0.93
Min Individual Policy Levers	0.20	2.07	1.59	0.88	0.72	0.88	0.60
Minimum Cost	0.18	1.53	1.37	0.83	0.68	0.96	0.65

Policy Levers

	Number of Suppliers	Contracts Per Supplier	Supplier Development	Inventory Levels	Contract Length	Joint Forecasting	Performance Measures	IPT Use
Base Case	1	1	1	50	1	1	1	1
Min Individual Policy Levers	0.2	0.2	1	10	3	0.75	0.75	0.75
Minimum Cost	0.2	0.2	1.5	10	2	0.75	0.75	0.75

While increased levels of supplier development increase personnel costs to work with suppliers, it also leads to reduced prices. As an individual policy lever, with contracts expiring in about one year and no assurances that a given supplier will receive the follow-on contract, additional supplier development efforts are cost prohibitive. However, increases in contract length allow more parts to be delivered on each contract, producing cost reductions great enough to suggest increases in supplier development efforts. As seen in Figure 38, in moderation these two policy levers (supplier development and increased contract length) work synergistically, with the maximum benefit occurring when both are employed together.

Figure 38: Cost vs. Contract Length and Supplier Development

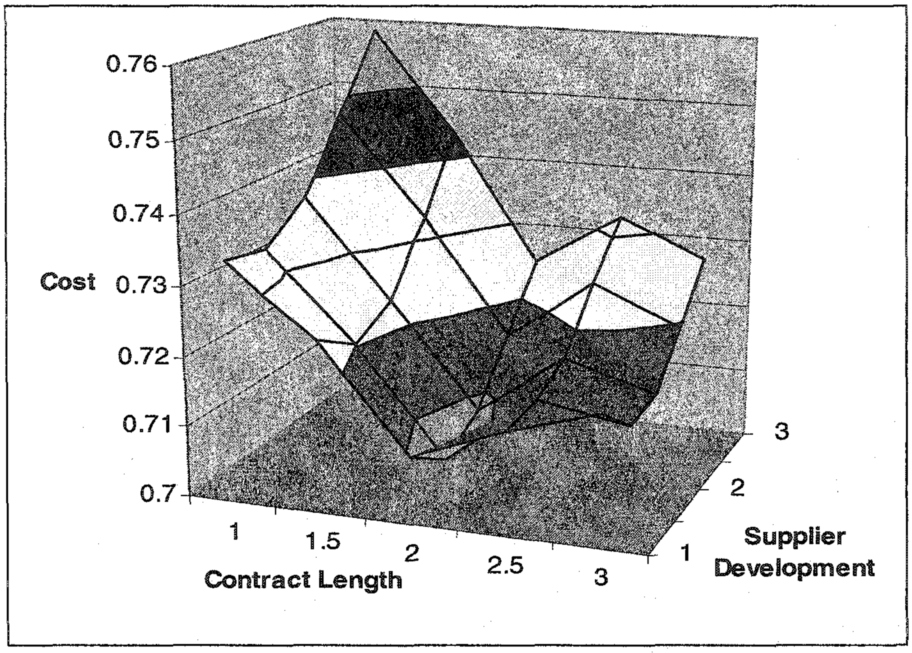


Figure 38shows that the minimum cost occurs with 50% more supplier development than the base case and an average contract length of 2 years. While longer contracts result in slightly lower prices, they also improve the delivery of parts by having fewer gaps in coverage raising inventory levels and inventory holding costs. Similarly, additional levels of supplier development, while improving performance, cost more to execute through increased transaction and personnel costs than are saved through reduced prices.

It must be pointed out that in the minimum cost case, not all cost categories are at their minimum. Transaction costs are actually higher due to the increased cost of additional supplier development and the increased difficulty and cost of awarding longer, more complex contracts. *Even when focused on cost reduction, reducing total costs may require additional expenditures in some areas.* For the current F100 engine parts dataset, due to their relatively high price, part costs dominate other cost categories and any actions that reduce the price paid for each part (such as additional supplier development) are often worthwhile even if they increase the other indirect cost categories.

Recommended Configuration

Arriving at a recommended configuration of the policy levers entailed further exploration of how the policy levers interact to influence outcome measures. Starting with the information learned while determining how to improve performance and cost independently, various combinations of the policy levers discussed below were considered and analyzed. By considering how the policy levers affect cost and performance, and using Analytica's ability to vary multiple policy levers at once, it was possible to learn how policy levers could be used to improve outcome measures while avoiding a majority of the "negative" consequences that occur when changing only one policy lever at a time.

This trade-off between performance and cost began with reviewing the macro effect of each individual lever, and determining if any of them had a consistently positive effect on both performance and cost. It was found that supplier development, while increasing two of the cost measures resulted in an overall lowering of total cost, while improving performance in all categories. This measure was set at its maximum value.

There were two other policy levers that in general operated independently from all others; the number of contracts per supplier and inventory levels.[156] Within the considered parameter ranges, the effect of adjusting these levers was consistent across all settings of the other seven levers. Thus, these levers could be set independently. As noted in the single parameter case, decreasing the number of contracts per supplier significantly improved cost but at a slight reduction in performance due to the use of larger more complex contracts that are more difficult to award and modify. Reducing the number of contracts per supplier to 60% of the baseline case achieves a majority of the cost savings while avoiding large reductions in performance. Similarly, maintaining the baseline inventory levels of an additional 50% of the required inventory to meet average demands balances the cost of holding additional inventory with improvements in responsiveness and quality.

With values established for three policy levers, the interaction of the remaining levers was analyzed to determine their recommended configuration. Figure 39 represents plots of composite performance and total cost for various levels of joint forecasting in the presence of different quantities of suppliers (different lines). As indicated by the downward slope of all performance plots,

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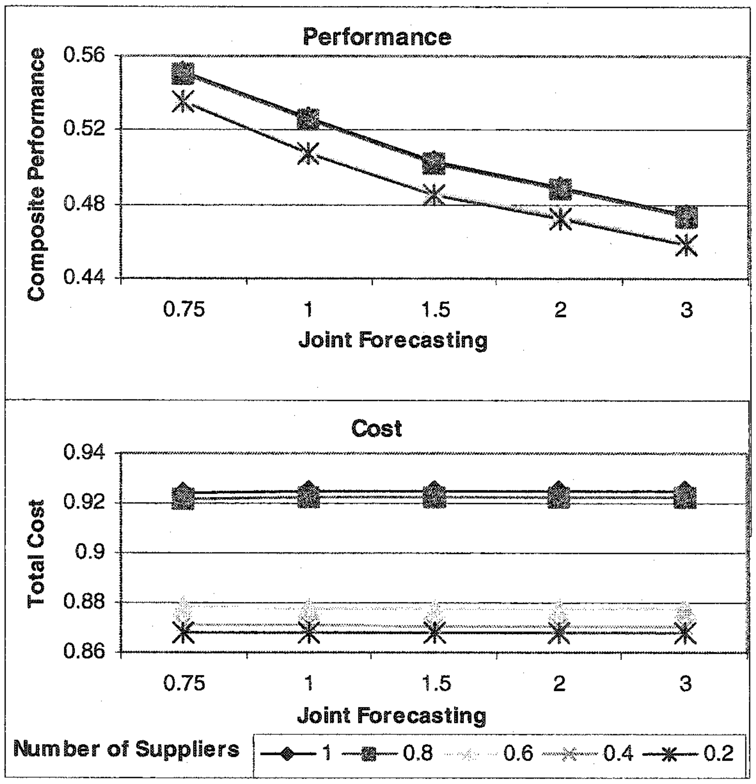
[156] While the number of parts kept in inventory varied with changes in other policy levers, changes to the inventory level policy lever does not prescribe an explicit quantity of parts but the percentage of basic inventory kept as safety stock for unanticipated demands. Thus, as designed the model allows the actual quantity of inventory to change regardless of the setting of the inventory level policy lever. This allows the inventory level policy lever to serve as a means of adjusting the performance of the PSM process according to the decision makers desire to minimize costs or improve performance.

increasing the presence of joint forecasting improves performance. Additionally, while difficult to see in the graph of costs, when the number of suppliers is reduced by 40% or more, increased levels of joint forecasting no longer increase total costs but result in slightly lower costs as the improvements in orders costs offset the increases in personnel costs required to conduct joint forecasting. When examining only these two policy levers, the lowest total cost and best overall performance comes from reducing the supply base as far as possible and maximizing the use joint forecasting.[157]

Figure 39: Interaction of Number of Suppliers and Joint Forecasting

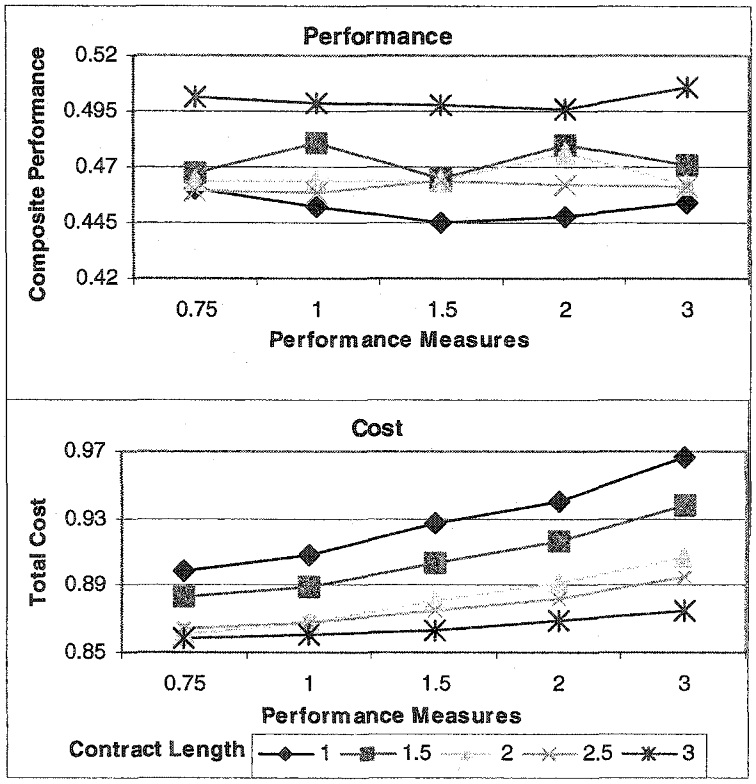


Similar to the interaction of the number of suppliers and the use of joint forecasting, when attempting to improve performance, the desired contract

[157] This is consistent with best business practices which find that for critical items such as engine spare parts, closer relationships with few suppliers is desired. For a discussion of how the nature of the part drives the type of relationship with suppliers, see the discussion of supply positioning in : Steele, Paul T. and Brian H. Court, "*Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness Through the Skills of Purchasing*," London: McGraw-Hill Book Company, 1996, Chapter 5. In practice, there are legal and practical limitations to the extent to which these policy levers can be employed, but as this varies by part and supplier, the exact number of suppliers or amount of joint forecasting possible is left to be determined during the implementation of any changes to the current PSM process.

length depends upon the extent to which performance measures are used. As seen in Figure 40, for a given amount of performance measures longer contracts (switching lines on the graph) decrease costs, suggesting that contract lengths should be as long as possible. However, when examining overall performance, decreasing the average contract length from 3 years to 2.5 years improves overall performance (the composite score improves from 0.50 to 0.46 with the baseline use of performance measures). This is due to the fact that the longer contracts and performance measures both increase contract award times. While initially, longer contracts improve the stability of the relationship with suppliers and reduce total contract award costs, average contract lengths over 2.5 years increases contract delays (and increases the length of time a contract is not available when needed) sufficiently to offset any performance improvements achieved by the additional performance measures or having the same contract in place longer. Balancing the desire to reduce costs with improving performance, the best combination of these two policy levers is an average contract length of 2.5 years and no change in the use of performance measures. This combination achieves most of the performance improvements with minimal cost increases. If proactive IPTs were used in the model, this number would likely increase as the percentage of time a contract is not available would be reduced.

Figure 40: Interaction of Contract Length and Use of Performance Measures



It is worth noting that when considering the policy levers individually, longer contracts had little effect on performance but increased total costs. With the increased use of supplier development, the increased transaction costs associated with longer contracts are largely offset by a decrease in average purchase price resulting from the ability for supplier development activities to take effect over the longer contract life. By combining the policy levers in this manner, longer contracts are recommended.

The final policy lever, the use of IPTs had little effect on overall performance or cost. Increases in IPT use would improve the quality of the parts being sourced but at an increased transaction cost. As there was no clear benefit from altering the status quo, no changes are recommended for this policy lever.[158] This recommendation would probably change if IPTs were modeled as proactive rather than reactive and hence there was no increase in contract award time associated with the additional use of IPTs.

With a potential candidate configuration of the policy levers established using this stepwise process, several additional configurations were considered to determine if this configuration represented a globally optimal solution, and the determination of the recommended configuration was not dependant upon the selection process. By starting with multiple combinations of the policy levers and using alternative adjustment processes failed to yield a configuration that resulted in better performance and cost. This suggests that the recommended configuration is not dependant on the selection process, but represents the arrangement of the policy levers that achieves the highest performance improvements without significant cost increases. As mentioned earlier, if additional cost or performance improvements are desired, this increase is accompanied by a notable decrease in the other category of outcome measures. For example, increasing inventory levels will improve performance but at additional costs, while decreasing the number of contracts per supplier will reduce costs but at the expense of performance. As shown in Table I, the model's recommended policy lever configuration improves performance in all categories as well as reducing costs for most categories.

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158 This limitation on the effectiveness of IPTs is partially due to the way in which IPTs were defined in the development of the model. This does not imply that the formation of commodity councils or other strategic planning groups to identify sources for future requirements and ensure parts are grouped properly for sourcing are not beneficial. The use of integrated teams for these activities was not included as part of this analysis.

Table I: Recommended Configuration

Output Measures

	Responsiveness	Adaptability	Quality	Price	Inventory Costs	Transaction Costs	Personnel Costs
Base Case	0.13	0.82	1.86	0.99	0.96	0.92	0.93
Recommended Configuration	0.06	0.65	1.07	0.82	0.90	1.75	0.69

Policy Levers

	Number of Suppliers	Contracts Per Supplier	Supplier Development	Inventory Levels	Contract Length	Joint Forecasting	Performance Measures	IPT Use
Base Case	1	1	1	50	1	1	1	1
Recommended Configuration	0.2	0.6	3	50	2.5	3	1	1

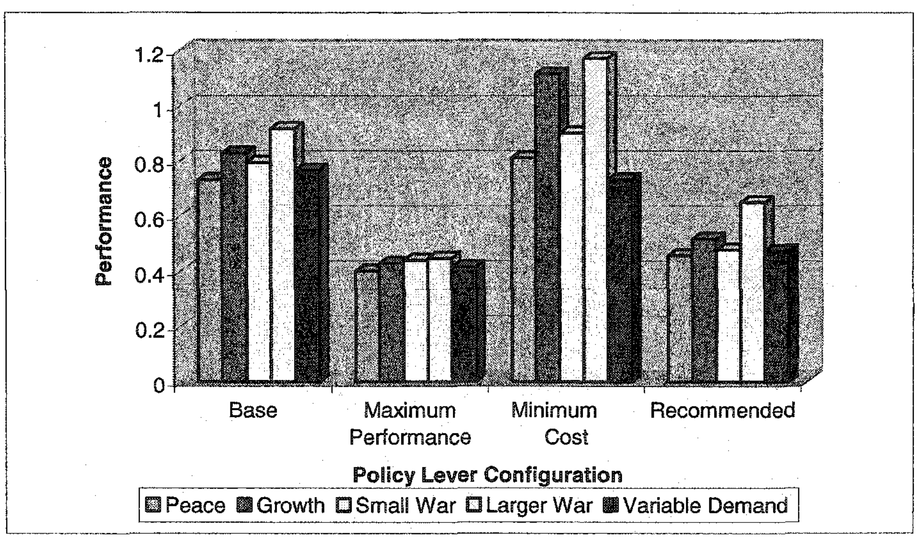
This configuration reduces total costs by 9% through more efficient relationships with fewer suppliers. With fewer contracts to manage, personnel can spend more time working with suppliers; developing joint forecasts of future requirements and to improving supplier performance through increased supplier development.

Robustness Across Scenario Variations

The final aspect that any configuration of PSM policy levers must consider when supporting Air Force weapon systems is the effect of a significant shift in demand patterns due to changes in mission profiles. To simulate different demand shifts, the PSM model contains four different demand scenarios in addition to the baseline "peace time" profile contained in the basic data set. Adding unplanned changes in the quantity of parts demanded ensures the PSM process as configured is robust to unanticipated events that could occur which would alter the quantity of parts required to support the F100 engine. These include a growth profile where demands double after 24 months, a small war where the growth last only for 12 months and ends after the third year, a larger war where demands triple for the 12 month period, and a variable demand pattern which cycles between a month of double demands, a baseline month, a month of half the normal demand, and back to the baseline demand. With these four different demand profiles, the performance of the PSM process, with the recommended configuration of policy levers, can be evaluated to ensure it does not become so efficient in handling the normal demand patterns it can no longer effectively support significant deviation from that profile.

As seen in Figure 41, all configurations presented in this section have the most difficulty maintaining performance under the larger war profile in which demands are tripled. This is reflected through increased customer wait time, additional backorders, and a lower percentage of parts with inventory. The profile designed to maximize performance best supports the increase to a larger war demand profile, with performance being relatively insensitive to changes in demand. Alternatively, the minimum cost configuration while performing well in the variable demand scenario has significant decreases (higher values) in performance for both the growth and large war profile. This configuration lacks the flexibility, inventory levels, and adaptability needed to respond quickly to the increased demand in these profiles. The recommended policy configuration, while experiencing a slight degradation in performance in the large war profile, also has the smallest loss of performance, with the more likely scenario of a smaller war, which could also be representative of an increase in training or other contingency such as the enforcement of no-fly zones after 9/11.

Figure 41: Varying Demand Profiles



As indicated in Figure 42 and Figure 43, the model's recommended policy improves responsiveness and quality from the baseline configuration for all demand profiles. The performance measure of adaptability is slightly worse in the recommended configuration due to an increase in average response time

(Figure 44). With a longer average contract length and fewer contracts per supplier, modifying these longer more complex contracts takes more time resulting in longer delays in recovering from an unforecasted increase in demand. In reality, during large conflicts special incentives and waivers from contracting rules and procedures are often granted mitigating this adverse effect, but the ability to handle these special one-time conditions are not included in the current version of the PSM model. As noted earlier, if this degradation in performance during the initial periods of increased demand is not acceptable, holding additional inventory provides the PSM process time to adjust to the increased demand. As expected, costs increase with the demand for additional parts for all policy lever configurations, but exhibit no unique or interesting patterns to warrant further discussion.

Figure 42: Responsiveness vs. Varying Demand Profiles

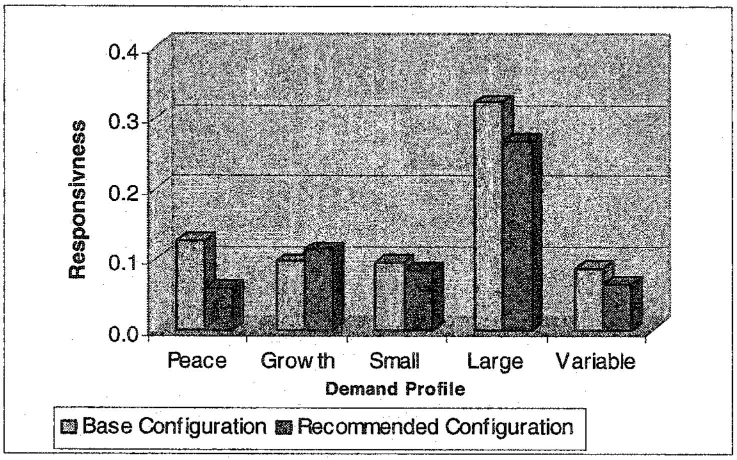


Figure 43: Quality vs. Varying Demand Profiles

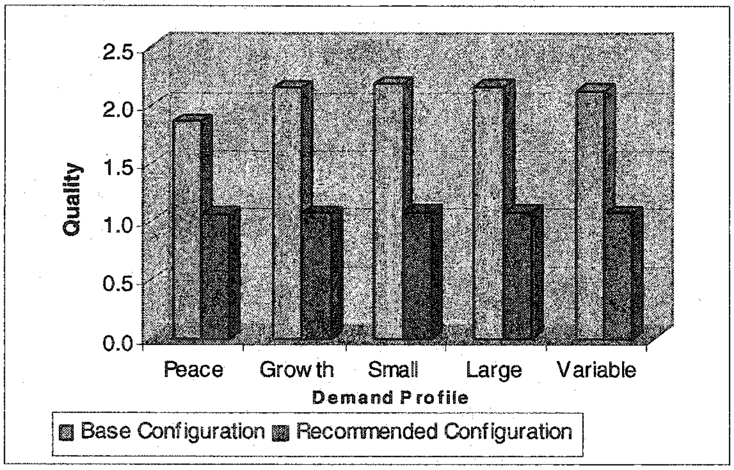
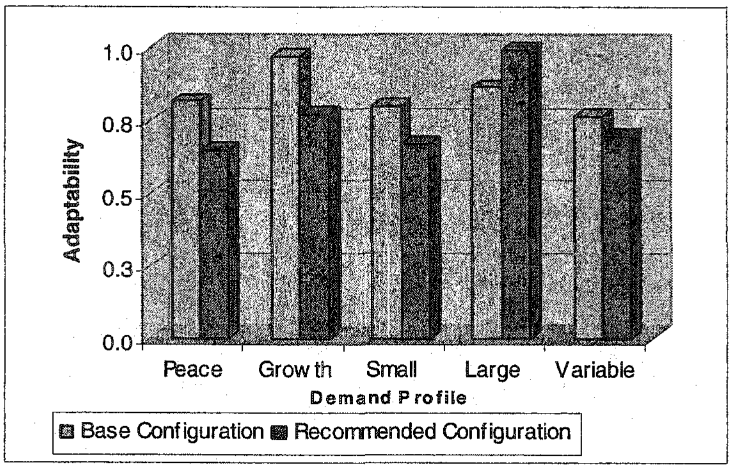


Figure 44: Adaptability vs. Varying Demand Profiles



Observations and Policy Recommendations

After reviewing the interaction of the policy levers, and developing a recommended configuration of the policy levers that improves both performance and cost, a number of observations can be made regarding policy changes that should improve the spare parts support provided to the F100 engine. These include observations regarding how the various policy levers interact, the key policy levers that produce the most significant improvement, as well as policy levers and model parameters that have little effect on outcome measures. As noted in the objectives of this dissertation, these recommendations reflect general trends that should improve the support provided by the PSM process to the F100 engine, rather than specific values regarding the number of suppliers or length of a particular contract. While further research is needed to provide this level of precision, it is possible to provide some observations, which lead to policy recommendations. Specifically the following observations and policy recommendations are offered.

Key policy levers

Number of Suppliers: While there are several policy levers that improve performance or reduce costs, many of them depend on a reduction in the number of suppliers to be a cost effective means of improving performance. This aspect of the model is consistent with commercial examples that suggest the first step in transforming an organization's PSM process is to reduce the supply base where possible[159].

Supplier Development and Joint Forecasting: After reducing the supply base to key suppliers, supplier development and joint forecasting efforts can be undertaken to reduce cost. These policy levers produce the most significant improvements in performance as well as reducing the price of items through improvements to the supplier's business base and permitting suppliers to better plan for future requirements.[160]

Contract Length: The final policy lever with as strong influence on the performance of the PSM process is the average contract length. While longer contracts are not always best, the model suggests an extension of the average F100 contract length from just over 1 year in the current data set to an average of 2.5 years. Increases beyond this length require the assumption of a great deal of risk in writing contract terms that years in advance and further increase the complexity of the contract by adding additional clauses for future requirements. Therefore, while contract length should be increased from their current lengths, the model as designed does not recommend excessively long contracts for most parts. While on a case by case basis some parts may be well suited to contract lengths over 3 years, on average contracts should be limited to 2-3 years in length.

Policy levers with mixed effects

Unlike the aforementioned policy levers that seem to play a significant role in altering the cost and performance of the F100 PSM process; there are other levers whose effect is not clear. Either due to the way in which they were modeled or their inherent nature, they have no specific setting that performs best in all circumstances. For example, while increasing the use of IPTs improves contract quality, a corresponding increase in cost offsets the minor improvements in performance.[161] Likewise, the use of performance measures

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[159] In a survey of its readers, *Purchasing* magazine found 80% of the purchasers are taking steps to reduce the number of suppliers. Fitzgerald, Kevin R., "Profile of the Purchasing Professional," *Purchasing*, July 15, 1999, pp. 74-84.

[160] This finding is consistent with that of recent business examples and perceived best practices. Trent, Robert J., "Applying TQM to SCM," *Supply Chain Management Review*, May/June 2001, pp. 70-78.

[161] As noted earlier, the limited affect of IPTs is largely an attribute of how they have been modeled to work within the current Air Force structure and operational procedures. If a more proactive approach to teaming is adopted, IPTs may have the much more pronounced effect found in the business literature. Trent, Robert J., "Individual and Collective Team Effort: A Vital Part of

had little effect on performance but came at an increased cost in time and money to award contracts. For this parameter, its seems that the lack of effect is largely attributable to the nature of the parts in the data set, but without analyzing other data sets this cannot be known for certain. Finally, sufficient inventory levels are needed to handle variations in demand, but once inventory levels are established to compensate for the variation in the demand for a particular part additional adjustments are unnecessary.

Critical parameters

In executing the model and conducting the exploratory analysis, it became apparent that several elements in the data seta and parameters in the model itself were critical to the model results. These data elements and relationships between the policy levers and model components should be the focus of any additional efforts to improve the accuracy of the model. Changes in the three parameters identified in this section can cause significant variation in the results.

Particularly for jet engine parts, the price paid for parts greatly overwhelms the other indirect cost categories (in the base case, part costs represent 96% of the average monthly cost). While this may not be the case for other types of parts, in this analysis all links between the policy levers and the price of the parts were carefully monitored to ensure that the proper effects of varying the policy levers were captured in the model. These links were reviewed after the model's design, confirmed during discussions with personnel from Oklahoma City ALC, and are believed to be accurate for F100 engine parts, but may or may not reflect the design of all PSM processes within the Air Force.

The dominance of part costs over other cost categories makes it difficult to ascertain changes in other cost categories when comparing two different policy configurations, necessitating the monitoring of costs for each individual cost measure. As the Air Force does not explicitly track costs for these indirect categories (inventory holding, transaction, and personnel costs) calibrating the model to actual costs in these areas is difficult. Thus, the numerical results from changes to these categories, while accurate in relative terms may not be completely representative of the dollar adjustments realized when changing policy levers in the real world.

Sourcing Team Success," *International Journal of Purchasing and Materials Management*, Fall 1998, pp. 46-54.

The second critical data element that was difficult to determine with great precision, is the basic contract length for each part. As discussed in Appendix B, there is not a database containing the actual contract length used for each part making the accuracy of this data suspect. Contract length affects not only the amount of time a part remains on contract between renewals driving transaction costs, but it also indirectly affects the effectiveness of other policy levers such as the use of performance measures, and the efficacy of joint forecasting and supplier development.

The final data element that played a critical role in the performance of the model was the production lead time of each part. As this varied from a month to over 2 years (See Figure 69 in Appendix B for the distribution of the production lead times), the potential for improvement by reducing production lead times is significant. Unlike delivery times, production lead times are also highly sensitive to changes in the PSM policy levers. Unlike contract award times which are largely driven by statutory requirements, production lead times are not only important in responding to unanticipated demands, they represent an area where improvement is possible for many parts.

Regarding the inter-model parameters, the performance measures are highly sensitive to increases in contract award time. The model currently considers this the time between the expiration of a contract and the award of a follow-on contract. It is understood that in many cases, this delay is zero as the follow-on contract can be awarded while the current contract is still in place. However, because it is not possible to know for which parts this occurs, the model assumes that all parts experience a portion of time without a contract in place. While this fails to correctly model a particular part, for the entire data set this, on average, results in a percentage of the demands not having a contract in place when needed as occurs in actual operations.[162] In the model, this gap in coverage is responsible for many of the backorder delays and directly contributes to increases in response time. In reality, efforts are made to ensure a contract is in place for as many of the parts as possible, reducing the percentage of time the average part spends without a contract. The use of a form of IPTs called commodity councils to develop proactive sourcing strategies is one possible method of reducing the average gap in coverage, by ensuring a contract is in place for those high demand parts.

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[162] While the Air Force is currently working to improve the percentage of parts that are on contract at all times, gaps in contract coverage still occur when parts that are not expected to fail are damaged or require replacement. The specific percentage of the time this occurs is not known using currently available data sources.

7. Conclusions

This dissertation has shown that policy and organizational changes in the PSM process have the potential to improve effectiveness while maintaining or lowering costs. It has also demonstrated that a system dynamic model used with can provide an important contribution to defining, discussing, and understanding the complex interactions between policy levers and outcome measures particularly in enhancing PSM efficiency and effectiveness. The model served as a helpful aid to facilitate discussion with all levels of personnel. By facilitating an in-depth exploratory analysis into the interaction of the PSM policy levers, insights were gained into how the PSM process interacts that were previously not well understood. Moreover, by populating the model with a specific data set, broad policy recommendations were formulated that when implemented should improve the support provided to the F100 engine at a reduced overall cost.

This analysis concludes with a summary of the policy recommendations gained and the limitations of this analysis while developing and executing a system dynamic model of the PSM process. In addition to reviewing policy changes related to the support of the F100 engine, areas of additional research, and a discussion regarding the potential of system dynamic models to support future policy issues. This chapter concludes with some comments regarding how to implement these recommendations.

Summary of Findings

It was determined that a system dynamic model could be used to represent the operation of the PSM process and demonstrate how changes in policy levers can improve performance and reduce costs. Unlike complex mathematical models implemented in traditional procedural computer languages which are difficult to interpret, a system dynamic model with its pictorial display of the process being modeled and emphasis on feedback loops is well suited to support discussions regarding the nature of the PSM process and how policy levers interact to change outcome measures of interest. The design and nature of this type of model allows for the interactive development involving managers, functional experts, and policy analysts jointly developing the model of the PSM process. In addition to clarifying how the policy levers interact, and providing insight into how change to these levers directly affect outcome measures of interest several recommended changes to the current PSM process used to support the F100 were developed.

One of the most important implications of this effort is the benefit of combining areas of expertise into one study. This analysis required knowledge of purchasing and supply chain management practices (for both commercial and military settings) as well as access to economic theory and exploratory modeling techniques. By combining all these areas of expertise, a better understanding of the dynamics of the PSM process is possible. This type of multi-discipline research is critical in today's interconnected world.

As indicated in Table J, the dissertation provides analytical support for the adjustment of several policy levers with respect to the PSM process used to support the F100 engine. With fewer suppliers, the cost of conducting supplier development and joint forecasting are lowered allowing performance to improve with minimal changes to cost. In this improved operating environment fewer, longer contracts with key suppliers improve efficiency and reduce contract award costs. Inventory levels and the use of performance measures or IPTs, as they are currently employed, are recommended to remain at the current levels. While achieving this configuration will require increased transaction costs and a change in how the Air Force views suppliers, the potential performance and cost improvements appear to be significant.

Table J: Summary of Policy Recommendations

Policy Lever	Recommended Change
Number of Suppliers[163]	Major reductions in the supply base where possible.
Contracts Per Supplier	Consolidate individual contracts to reduce the total number of contracts by about half where possible.
Supplier Development	Increase supplier development efforts significantly. This should include working with suppliers to improve their production process as well as improving the transactional efficiency in which the Air Force and Suppliers interact.
Inventory Levels	Adjust as needed to respond to potential surges

[163] As noted earlier, it is assumed that reductions in the number of suppliers that the Air Force does business with will increase the leverage it has with the remaining suppliers, without greatly increasing the monopoly power of the remaining suppliers. Thereby reducing price and improving the quality of the parts provided by those suppliers chosen for their ability to provide this level of service. For a more detailed discussion of this and other assumptions used in developing the PSM model and these recommendations see Appendix C.

	in demand.
Contract Length	Increase contact length to several years on average.
Joint Forecasting	Significantly expand the use of joint forecasting with all key suppliers.
Use of Performance Measures	No change from current practices.
Use of IPTs	No change from current practices.

Implementing these policy recommendations requires a shift from the current short-term transactional focus, to a much more integrated link between the Air Force and suppliers. However, as seen in various commercial examples and demonstrated through the execution of the model developed in this study, achieving efficient and effective support to Air Force weapon systems requires such a transformation.

The results of this analysis highlight the need for a balanced approach to designing the PSM process to include multiple outcome measures of performance and cost. Increases in spending in a particular area may be needed to achieve more significant reductions elsewhere. For the current data set of F100 engine parts, due to their relatively high cost, the price paid for parts dominates other cost categories and any actions that reduce part costs are often worthwhile even if they increase the other indirect cost categories. In particular, more effort and money should be spent working with suppliers through increased joint forecasting and supplier development to reduce the cost of the parts purchased and thereby reduce the total cost of providing spare part support for the F100 engine.

How well these recommendations apply to other engines with the Air Force, or to other goods and services both in the Air Force and for supply chains in general have not been formally tested. As many of the functional forms and the parameterization of those functional forms have been based upon the processes and expectations of the Oklahoma City ALC, the results of this analysis should be similar for other sets of jet engine parts sourced by the Oklahoma City ALC. However, expanding the scope of applicability to non-engine parts or to other ALCs within the Air Force is not advised without exploring how well these functional forms and parameters apply to operations outside Oklahoma City.

For example, the model assumes that changes in the number of suppliers used by the Air Force does not alter the number or relative size of the companies in the supply base. For jet engine parts, where commercial airlines who fly many more aircraft than the Air Force, this assumption is thought to be reasonable and reflect the actual operation of the jet engine spare part's market. However, for other markets such as the purchase of satellite components, the Air Force is a much larger percentage of the market place and changes in the number of suppliers used by the Air Force could alter the number of suppliers present in the market. For example, if the Air Force reduces the number of companies for which it does business, those companies not receiving contracts from the Air Force may be forced to go out of business or merge into larger enterprises to take advantage of economies of scale and scope.

Similarly, as the model has been designed to reflect how the Air Force interacts with suppliers it may or may not apply to other non-governmental enterprises. Commercial firms, with different procurement rules and regulations may have significant differences in how their PSM process operates that would require adjustment to the design of the PSM model as well as revisions to the functions forms and parameters used to populate the model. For example, as commercial firms do not have the ability to demand cost and pricing data under the Truth in Negotiations Act,[164] the pricing of parts may be more susceptible to monopolistic pricing. Therefore, for commercial companies reducing the number of suppliers may have a different effect on the prices charged by the remaining suppliers. The nature of this relationship and how it varies between government and commercial buyers has not been explored in this analysis.

Generalizability

The model developed in this study was designed not to just support the determination of how to best configure the PSM process supporting the F100 engine. As noted in the literature on supply positioning, one approach does not fit all types of goods and services.[165] The PSM process must be tailored to the types of items being purchased as well as the nature of the supply base providing those parts. With changes to the model's cost factors and adjustments to weights assigned to the various outcome measures, it could be used for any set of goods or services that are purchased from a variety of sources. The ability of the model to handle different types of goods or services with different

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[164] For information on how and when government contracting officers can and must request cost or pricing data see: Federal Acquisition Regulation, *Subpart 15.4 - Contract Pricing*, current through May 22, 2003. Online at http://www.arnet.gov/far/. (as of June 9, 2003).

[165] For a discussion of how the nature of the part drives the type of relationship with suppliers, see the discussion of supply positioning in : Steele, Paul T. and Brian H. Court, "*Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness Through the Skills of Purchasing*," London: McGraw-Hill Book Company, 1996, Chapter 5, or Kraljic, Peter, "Purchasing Must Become Supply Management," *Harvard Business Review*, September-October 1983.

characteristics has yet to be documented. This would include parts with more suppliers, parts with lower costs, shorter production lead times, or even the purchase of services that are not physical parts such as grounds maintenance or office equipment repair. While the model was designed to be easily modified to handle these different types of items, this design feature has yet to be tested. Executing the model with additional data sets would also further the understanding of which PSM levers should vary according to the types of parts and which are universally beneficial. At this time, the recommendations of this study can only be conclusively applied to the PSM process supporting the F100 engine subject to the model's limitations previously mentioned.

It is believed that the model developed for this dissertation can be used for other sets of parts to include non-weapon system parts such as furnishings or other base support items or other types of goods and services. The basic environment needed for all of the model's outcome measures to be meaningful are a list of goods or services purchased from one or more suppliers who occasionally cannot meet all requirements with existing inventory levels (for services available personnel can be considered inventory). For a commodity group that never experiences this type of backorder, many of the model's features and metrics will not vary. For example, with no items delivered late, the response time would always be zero. However, those outcome measures that do vary, such as the quality of the goods or services or the speed in which they are delivered, still operate properly and offer some measure of how well the PSM process is functioning.

Thus, with little adjustment, the model should be capable of adapting to a different set of goods or services and the unique attributes associated with this new items list. Specifically, reconfiguring the model, without changing how the policy levers work or the functional forms and parameters used to represent these effects, requires two types of changes: the incorporation of new data files and the calibration of system parameters to reflect the performance of this new environment. The types of raw data needed, described in Appendix B, include the demand rates, production and delivery times for each item, as well as the number of suppliers and nature of the relationship with the existing supply base.

Future Research

This section provides some suggestions on how this effort could be expanded upon to include additional areas of research that are suggested by the findings of this study but beyond the scope of this effort.

Due to changes in the F100 PSM demonstration efforts at Oklahoma City ALC, it is not possible at this time to compare the findings of this study to real world changes in the actual support process. Over time as the effects of changing the Air Force PSM process are observed, the results of this study can be empirically compared to actual operations to strengthen the validity of the model's findings or suggest changes to the design or parameterization of the model.

While all of the causal links contained in the model can be refined and modified over time as the nature of the interaction of the components of the PSM process become better understood. Naturally, some areas are more critical than others. Within the existing model, two critical areas appear to be not well understood and therefore are not well represented in the model. The first is the appropriateness, benefits, and costs of using Integrated Product Teams to support spare part purchasing and management is not clear from the exploration of the current model. The current model limits the use of IPTs to those that can operate in the existing Air Force structure. Thus they are largely reactive to changes in demand, and fail to proactively increase the percentage of parts that are on contract at all times. While it is known that IPTs, by including a broad spectrum of participation and avoiding functional stovepipes, can improve the quality of the procurement process, exactly how they effect outcome measures of interest and when additional IPTs use is warranted is not clear. Similarly, the proper modeling of the contract award process and how the time and cost required to award a contract is affected by changes in PSM policy levers is critical to the proper operation of the model. Both of these areas warrant additional exploration to ensure they are better understood. If a better representation can be successfully made and properly captured in the model, it will improve the utility of the PSM model and the applicability of the recommendations suggested by the model's results.

One method to determine if a more proactive approach to identifying sources of supply would be to split the data into sub-sections according to the relative frequency of demand and importance of the part. Those high frequency, high demand parts represent parts whose contract never lapse due to active management by a commodity council or IPT. This would highlight the value of creating such an entity and further explore how the contract award process affects the performance and cost of the PSM process. Recognizing the importance of having a contract in place to source all parts, the Air Force has recently begun an effort to ensure that all parts of a weapon system are included on an active contract. The cost and performance impacts of this shift are being studied and may be incorporated into future versions of this model.

By taking a long-term view of the PSM process, this analysis does not explicitly capture the one time cost of implementing changes to the status quo to a more efficient PSM structure. It must be recognized that changing a system is usually not possible unless the existing organization is transformed to operate with the new procedures. Because it is difficult to quantitatively define the abilities of the current staff and the extent to which initial training and any changes to the existing recurring training that are required by the new procedures, implementation costs are not included in this model. The cost of this transformation, while minor in its magnitude compared to the amount of Air Force spending on purchasing goods and services must be included for any implementation plan to be successful.[166]

The final recommendation for future study would be the development of a similar model for other business practices. This could include decisions regarding the acquisition of new weapons systems, designing logistical processes or determining the best design of the support process used to repair or replace weapon systems and weapon system components. With the increased capability of today's computers and modern modeling software, system dynamic models are relatively easy to build and operate compared to models written in traditional procedural computer languages. As shown in this study, in addition to providing specific policy recommendations they are useful in helping to understand the interaction of a system as it evolves over time.

[166] As noted earlier, the Air Force is currently working to implement many of the PSM policies through the formation of a Purchasing and Supply Chain Management IPT at Headquarters Air Force Material Command. For details on the status of this effort see: Tinka, Marie and Scott Correll, " Improving Warfighter Readiness Through Purchasing and Supply Chain Management (PSCM) Transformation," HQ AFMC, PSCM IPT briefing, June 2003.

A. PSM Model

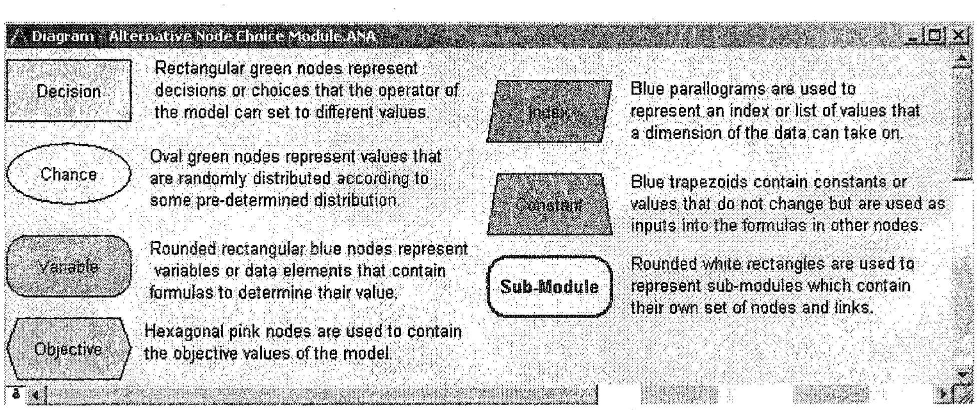
This appendix describes the Analytica modeling environment and the structure of the PSM model developed to support this dissertation. While primarily focused on how the model has been built, it also provides information on the operation of the model and features designed to simplify its operation for personnel with limited modeling experience.

This appendix primarily documents the model's structure, while the data used for the F100 test case is described in appendix B. The functional impact of the individual policy levers, seen in the model structure as links between the policy levers and other components of the PSM model are discussed in appendix C.

Modeling Environment

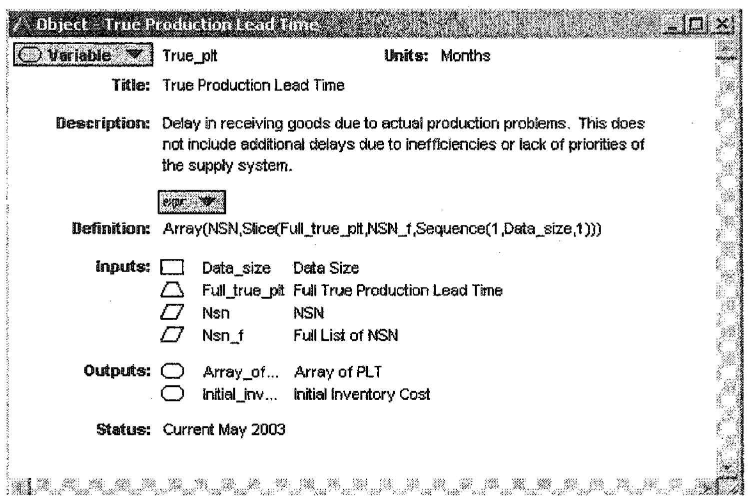
To represent various data tables, policy decisions, and outcomes Analytica uses different color codes and types of geometric figures for each class of objects (Figure 45). As seen in the figure, by changing not only the design but also the color of each class of node, it is immediately clear without opening the node the type of information contained therein. These nodes are joined into a model with arcs (links) that visually represent the interdependence between two nodes. Finally, to simplify the design, rather than requiring all nodes to be present in a particular module (screen) at one time, sub-modules can be used to develop more complex sub-routines that are represented by a single figure in the model.

Figure 45: Analytica Node Styles



Each node is composed of several data fields or elements as seen in Figure 46. These include fields to describe the contents of the node; the mathematical definition of the data contained in the node; and a list of other nodes used as inputs to this node or that use this node as an input. The final field STATUS was created by the author to serve as a holder of information regarding the source of the data used to define the node, the date the data was input, or how relationship described in the node was established. By using the description and status fields, the model becomes self-documenting and contains all the information needed to understand not only how it is operating but also where to find the original source of the information contained in each node.

Figure 46: Sample Analytica Input Template



In addition to viewing the fields containing structure of the nodes, it is possible to look at the resulting information contained in the node when the model is executed. Analytica presents the data as a table of values as in Figure 47 or as a graph (Figure 48). When displaying an array of data that has more than two dimensions, Analytica places toggle(s) for the remaining dimensions of the data above the table allowing the user to display different settings of these additional dimensions. This ability to easily manipulate multi-dimensional output arrays makes Analytica ideally suited for an exploratory analysis.

Figure 47: Sample Analytica Data Output

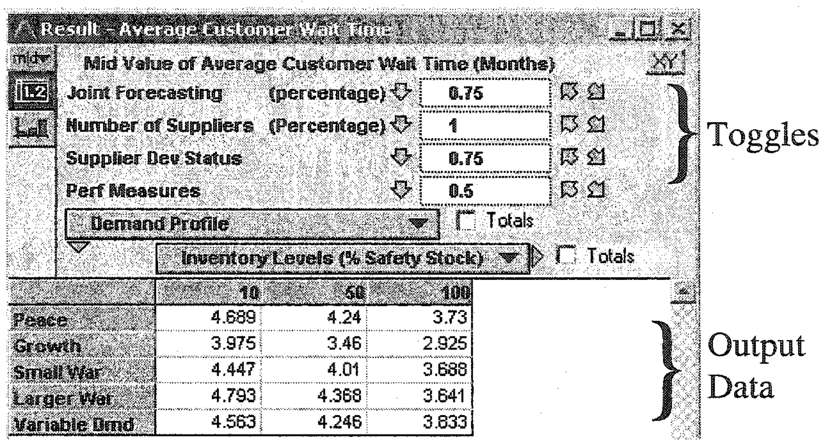
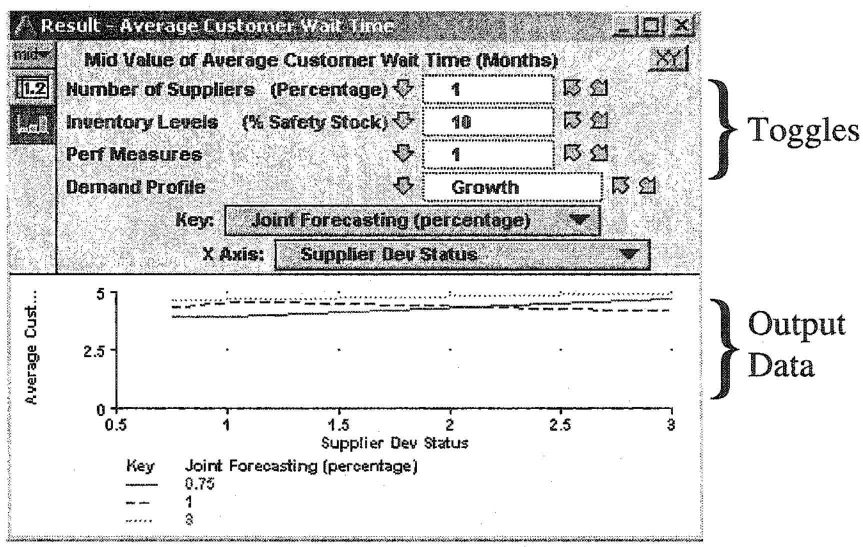


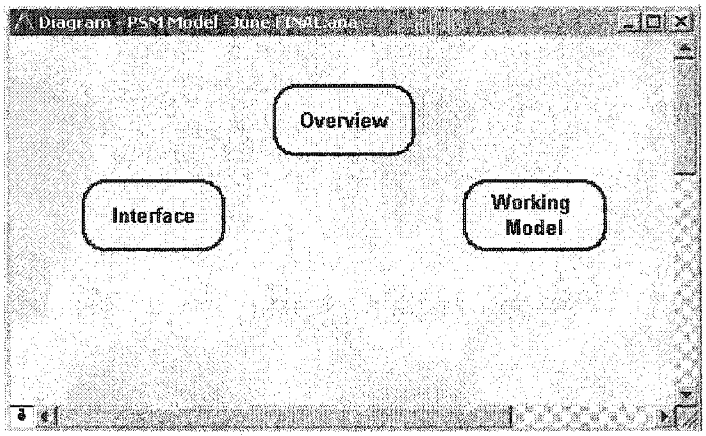
Figure 48: Sample Analytic Graphical Output



Overall Model Structure

To clearly distinguish between model components needed for its construction from those used during the operation of the model, a separate module was designed to separate the nodes used to interface with the model from the model itself (Figure 49). The interface module contains links to policy levers, model control parameters (i.e. the number of time periods in the model), and output measures of interest. The organization of this module facilitates model execution without the distraction of all of the required intermediate nodes. The working model module, containing the actual model is designed and structured to reflect the PSM process being simulated. A brief discussion of each of these modules is as follows.

Figure 49: PSM Model Structure



Interface

The interface module, represented in Figure 50, contains controls that allow the user to adjust all policy levers as well as links to all of the primary and secondary objectives. Selecting one of the input values shown in rectangles on the policy lever DDS module (Figure 51), assigns particular value or set of values to each policy lever. Similarly selecting one of the objective values represented by rounded ovals in the outcome measures DSS (Figure 52), displays its value or opens a more detailed window like the one in Figure 47 where the values of that objective can be easily seen for all selected combinations of the policy levers. This interface module also contains two sub-modules, which control the various parameters used by the model (such as the cost per order or the number of man-hours required to process a delivery order. See Figure 19 and Figure 20, in Chapter 4 for a description of these sub-modules). Locating links to all of the relevant input and model settings in this manner facilitates the exploration of the model without obfuscating the issue with unneeded detail regarding the model's mechanics.

Figure 50: Interface Module

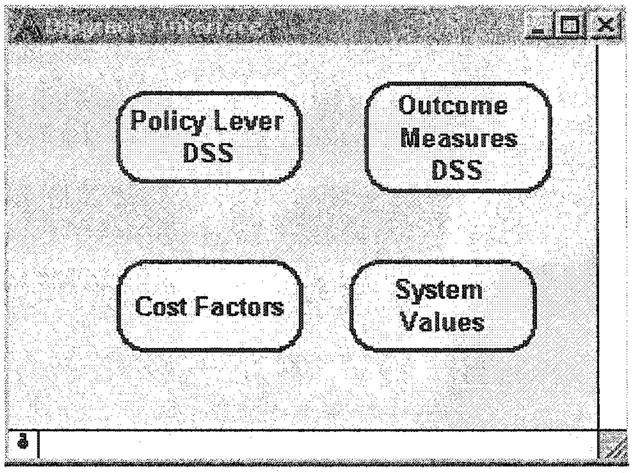


Figure 51: Policy Lever Sub-Module

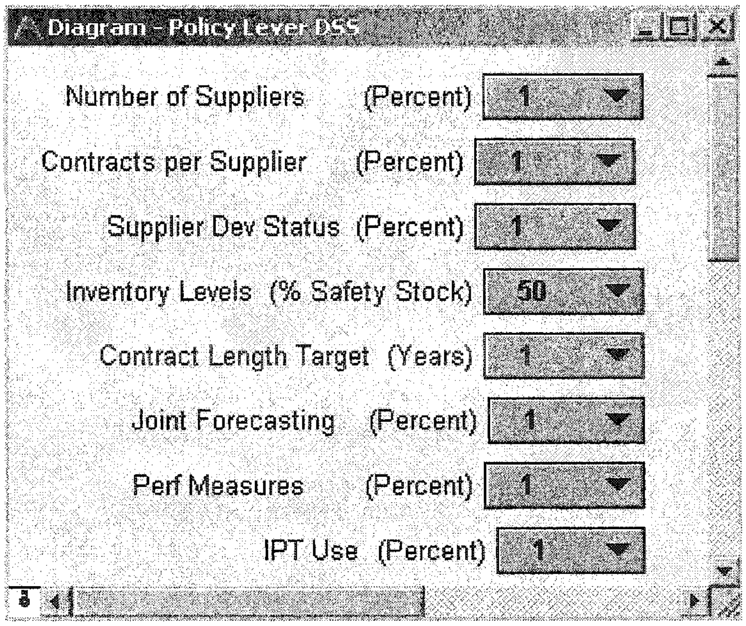
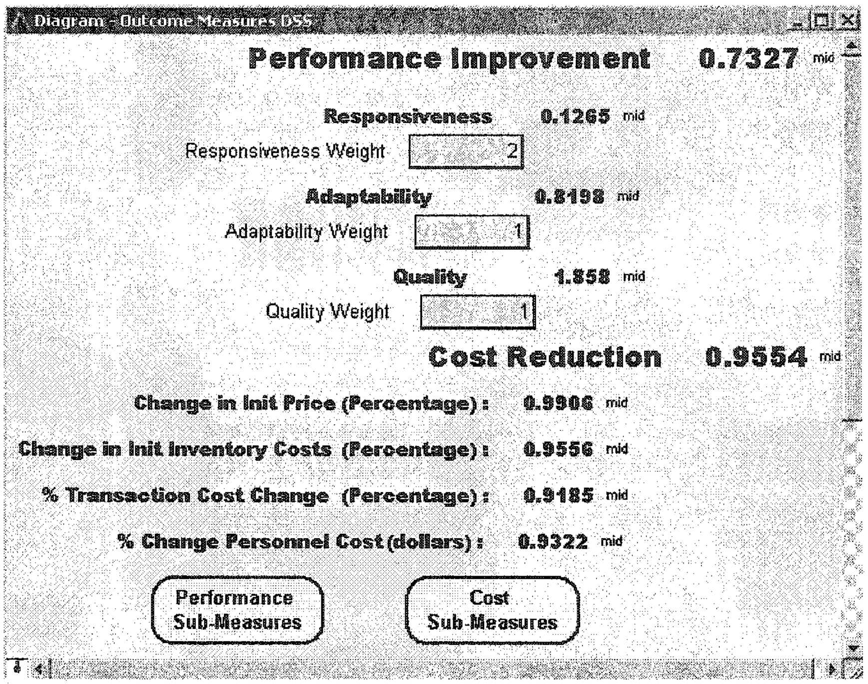


Figure 52: Outcome Measures DSS Sub-Module

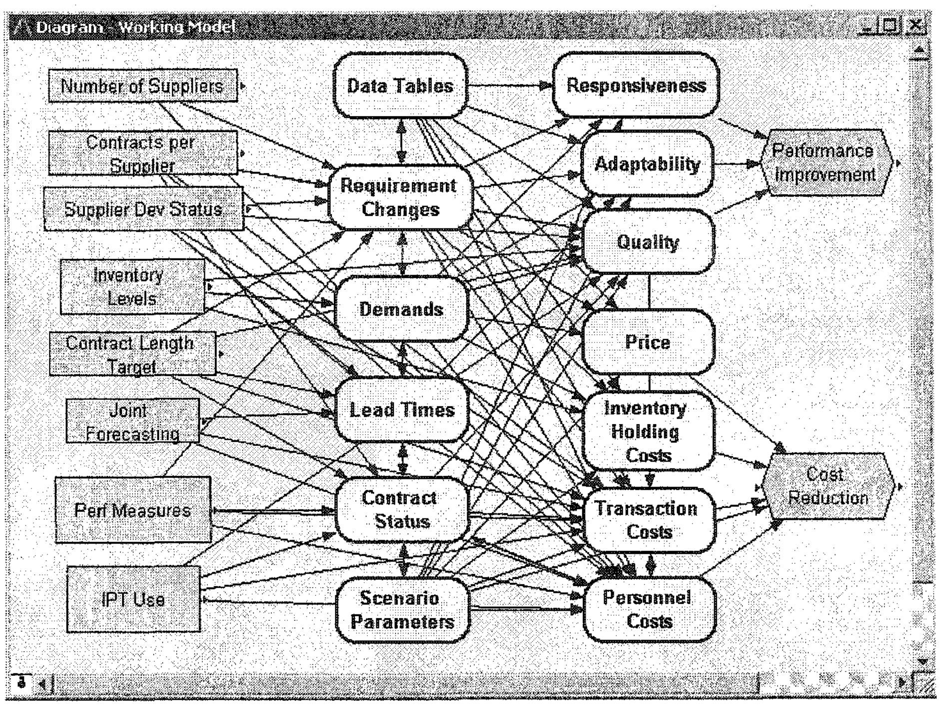


Working Model

The simulation model itself is composed of a set of input nodes for each of the policy levers, a set of modeling nodes containing the data and mechanics needed to represent the PSM process that link the policy levers to measures of interest, and seven output modules containing the structural relationships needed to compute various output measures. This section of the appendix describes the overall structure of the working model as well as key sub-sections.

Figure 53 displays the overall model structure to include the various policy levers and sub-modules as well as the links that interconnect them. While these links are helpful in visually demonstrating the complex interrelationship between the policy levers and the performance measures, they must be interpreted with caution as the absence of a link from one node to another does not imply that the two are not connected by an indirect relationship involving intermediate nodes in the model. For example, it appears that the policy lever "Number of Suppliers" only affects two other areas: the requirements changes and personnel costs. However, as the model is constructed the policy lever "Number of Suppliers" only reflects the targeted adjustment to the size of the supply base. Additional nodes are needed to convert this target into actual changes in the number of suppliers of each individual part. The requirement changes sub-module contains additional nodes that adjust the actual number of suppliers in the supply base for each part, which, in turn, affects a variety of additional model components. Due to the complex interaction of the model's components over time, achieving a complete understanding of how changes to a particular policy lever affect the model necessitates conducting an exploratory analysis where this lever is adjusted (along with others) and the effects are noted.

Figure 53: PSM Model Module

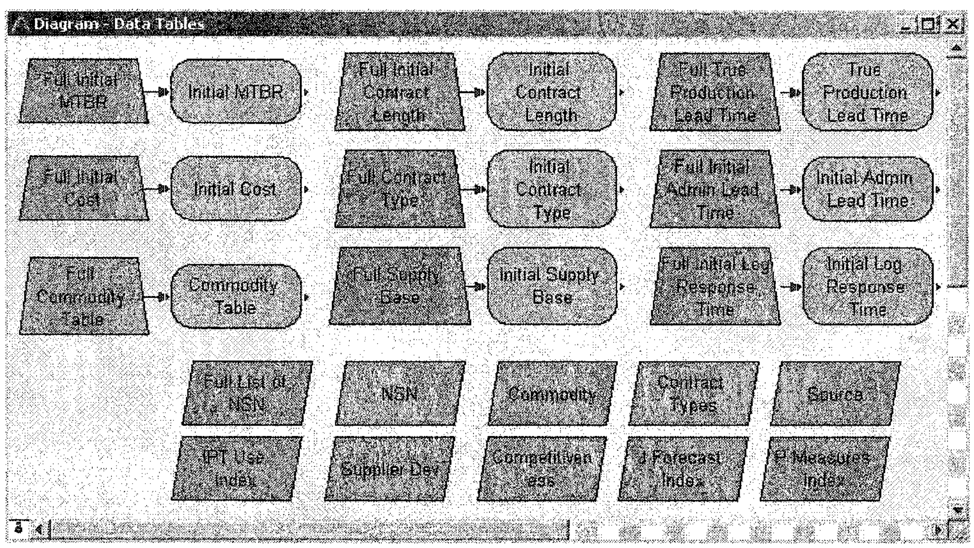


Data Tables

Like most quantitative models, the model of the PSM process developed in this dissertation requires a significant quantity of source data regarding the nature of the parts being evaluated. Source data is stored in 9 different data tables as shown in Figure 54. This also highlights two additional features of Analytica in general, and the PSM model used in this analysis. First, Analytica uses a variety of indexes to identify and define the dimensions of the arrays of data. These indices, identified by parallelograms in the bottom of Figure 54, contain the list of titles assigned to each element of a particular dimension. For example, the index "NSN" contains a list of the titles of all NSNs used in the current model run. The second unique feature of the data tables used in this model is the ability to limit the analysis to only a portion of the entire list of

NSNs when running the model. Limiting the analysis to a smaller number of parts (the first n NSNs) speeds the execution of the model, allowing the completion of more model runs in a given amount of time. Upon achieving a general understanding of the model's performance, repeating the analysis on the entire data set ensures the findings are robust to the full range of parts. In the data table module, the oval nodes contain this reduced list of data without losing the full data sets contained in each input data table represented as a trapezoid. For an explanation of the data contained in each of these tables as well as its source for the parts of the F100 engine modeled in this dissertation see appendix B.

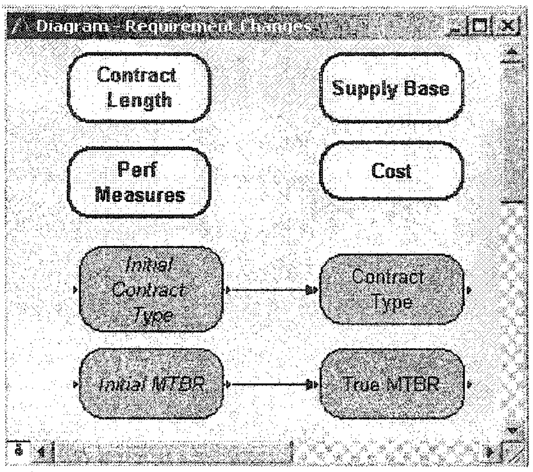
Figure 54: Data Tables Module



Requirement Changes

The requirement changes module takes the basic data from the data tables and adjusts these values based on the settings of the policy levers. As seen in Figure 55, contract length, the size of the supply base, the effectiveness of performance measures, and the cost of each part changes with changes in one or more PSM policy lever, while the basic failure rates and contract type are not changed by changes in the policy levers.

Figure 55: Requirement Changes Module



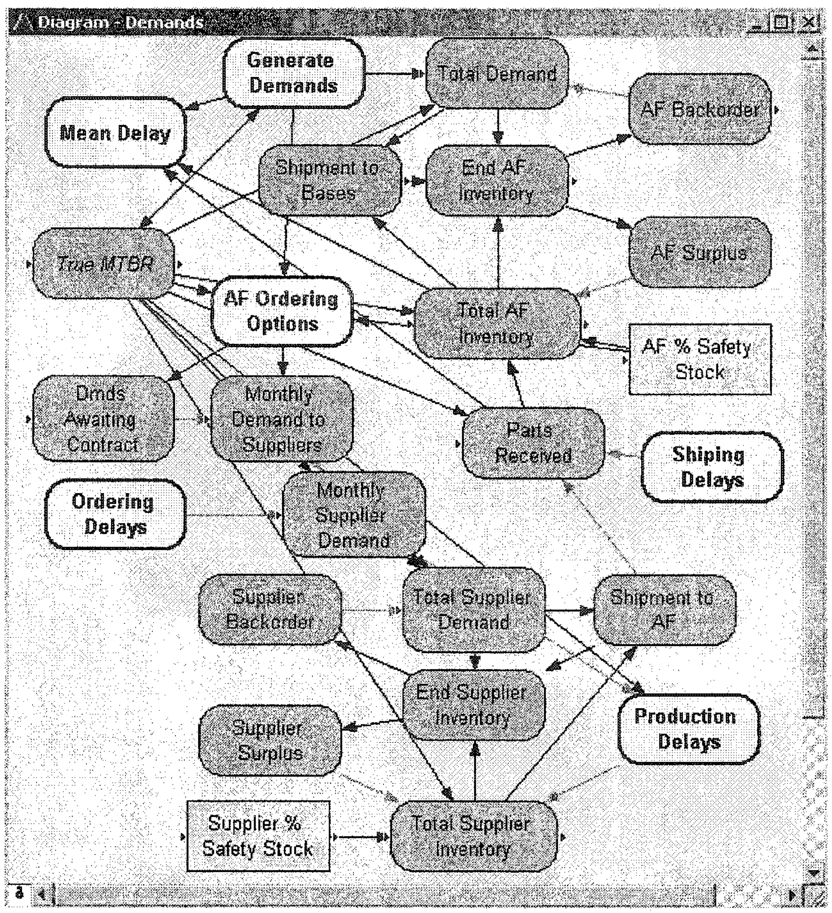
The sub-modules for contract length, supply base, performance measures, and cost take the raw data files found in Figure 54 and adjust them when various policy levers are changed. For example, the policy lever of contact length target sets the desired average, the contract length sub-module then take the initial distribution of contract lengths and adjusts them to meet this desired average. Similarly, as discussed in appendix C, the effective level of performance measures used not only depends upon the policy lever of performance measures, but the number of contracts per supplier. The performance measures sub-module combines these two inputs into a node representing the effective level of performance measures present as a result of the configuration of all policy levers. Similarily, the supply base sub-module takes the actual number of suppliers for each part and adjusts this to reflect the desired reduction in the supply base set by the number of suppliers policy lever. Finally, the cost sub-module adjusts the initial price of each part by a variety of policy levers noted in appendix C to produce a true cost paid for each part for each month of the model run.

Demands

The core of the PSM process is the flow of demands to the supplier and parts back to the Air Force. Figure 56 captures this flow. The process starts in the "Generate Demands" sub-module located in the upper left, which takes the requisition rate for each part and for each scenario and generates a list of demands by part and month. These are currently modeled as a Poisson distribution with a λ = the average part requisition rate which is determined by the base requisition rate from the data tables in Figure 54 adjusted for any changes in demand rates present when modeling alternative scenarios other than the base case. These demands are then met with existing inventory or placed in backorder status. Based on the ordering method selected, the model then places an order with the supplier (assuming a contract is in place and after an administrative ordering delay). The supplier then takes this demand for a part by the Air Force and either sources it from within the supplier's inventory or produces the part, with a production delay. Finally, the supplier ships the part, with a shipping delay, to the Air Force where it becomes part of the inventory of parts to meet backorders or future demands.

The execution of this order and ship cycle produces information regarding the quantity of parts demanded, as well as the number of parts in inventory or on backorder each month. Although not explicitly shown in this appendix, the Mean Delay sub-module collects the raw performance data from the Demands module and processes that data into usable information regarding the amount of time required to meet each demand.

Figure 56: Demands Module



Lead Times

As lead times serve a key role in the PSM process they have been separately placed in the lead times module (Figure 57). Like the requirement changes module, this module takes the basic lead times from the data tables and adjusts these values based on the settings of the policy levers. While delivery time from the supplier to the Air Force (Logistics Response Time) is unaffected by changes to the PSM policy levers, both production lead time and administrative lead times can be altered by changes to the policy levers.

Figure 57: Lead Times Module

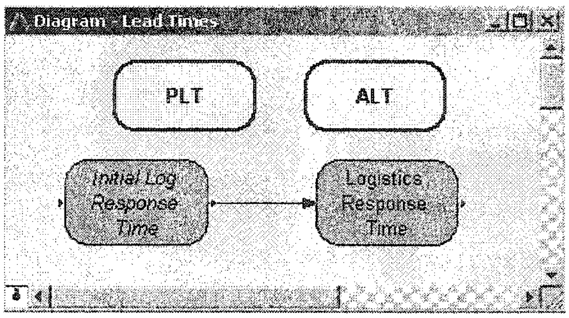
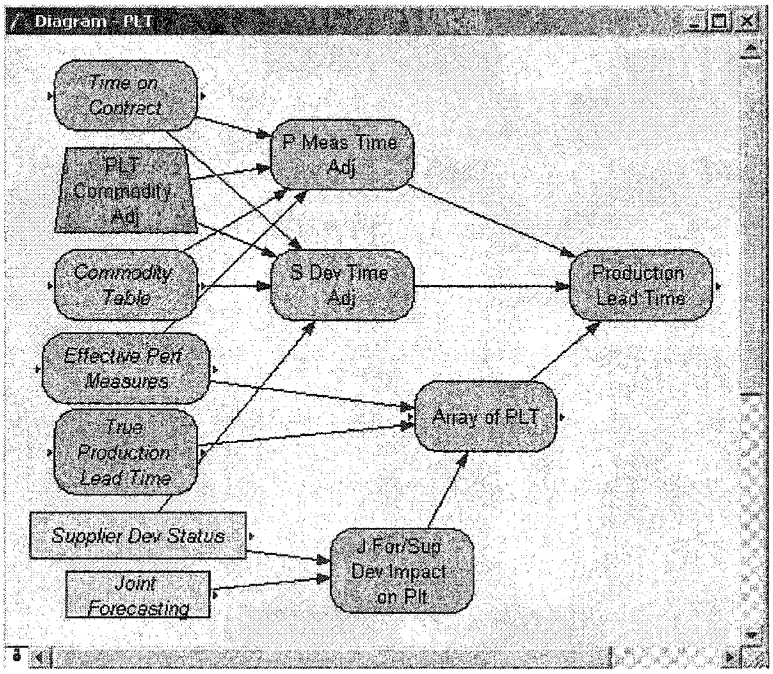


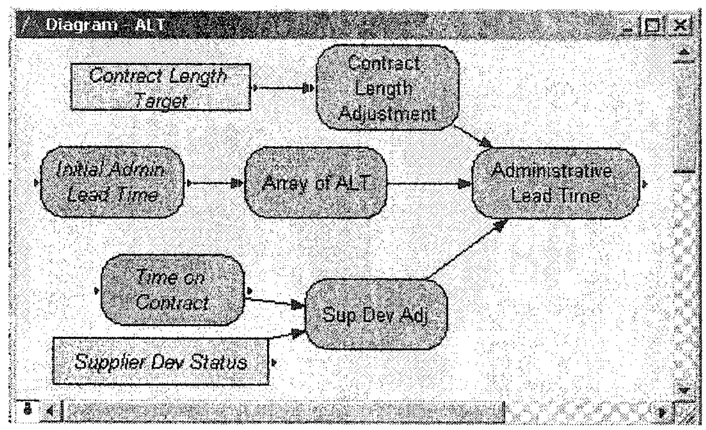
Figure 58 shows how the PLT sub-module adjusts the initial production lead times with varying degrees of supplier development, performance measures, and joint forecasting. These changes can vary not only by individual part or commodity (collection of parts with similar attributes) but by the amount of time the current contract has been in place. The nature of these changes such as the fact that increases in supplier development decrease production lead times is documented in Appendix C. The PLT sub-module produces a matrix of lead times by part that are used by the demands module to determine how long it takes suppliers to produce parts ordered by the Air Force, but not currently in the suppliers inventory.

Figure 58: Production lead time sub-module



Similar to production lead time, administrative lead times are affected by the contract length, the amount of time the current contract has been in place, as well as the level of supplier development efforts (Figure 59). This sub-module produces a matrix of administrative lead times to be used as an input into the demands module when determining the delay between establishing a requirement to order parts from a supplier and the actual receipt of that order by the supplier.

Figure 59: Administrative lead time sub-module



Contract Status

The final sub-module which captures the mechanics of the PSM process determines the contract status of each individual part. Figure 60 illustrates how the module generates a random sampling of contract award times based upon the range of possible award times.[167] The model uses this award friction to generate an Average Contract Delay for each part and month. Upon expiration of the existing contract, the model begins the re-award process. The primary output of this sub-module is a matrix indicating when contracts are awarded which is used as an input in computing contract award costs, and a matrix indicating which parts are on contract for each period.

Unlike the actual process used at an ALC where some contracts are re-awarded prior to the expiration of the current contract, the model has no mechanism to identify these parts. While one of the key components of PSM is

[167] This range is dependant upon the configuration of the policy levers and the basic nature of the variance in award times. After discussions personnel from Oklahoma City ALC, it was determined that for the current business practices used when re-awarding F100 spare parts contracts a triangular distribution of award times with a min of 1 month, a mode of 4 months, and a max of 10 months would best represent the initial variance in contract award times. The policy levers can adjust these distribution parameters as noted in Appendix C.

the need to segment an organizations spending into categories,[168] with different types of contracts and different award procedures used for each category. For example, critical parts and those that fail often would always have a source of supply (or two) while those items that only fail occasionally would be contracted for only when needed. Without completing this segmentation PSM model cannot differentiate between categories of parts.

To reflect the fact that parts with unplanned demands may not have a contract in place when a demand occurs, all parts are assumed to have a small lapse in contract coverage. The size of this lapse varies by the complexity of awarding contracts as well as the nature of the parts included in the model. With a large percentage of jet engine demands unplanned,[169] the model assumes that this gap in coverage is half of the normal delay to reflecting the fact that about half of the parts would normally be without a contract.[170] This sub-module attempts to always maintain a contract in place for all parts, but allows the contracts for all parts to lapse. While this is not an exact replication of the process used at the ALCs, it reflects the fact that in general contracts do expire and parts are needed when a contract is not in place.

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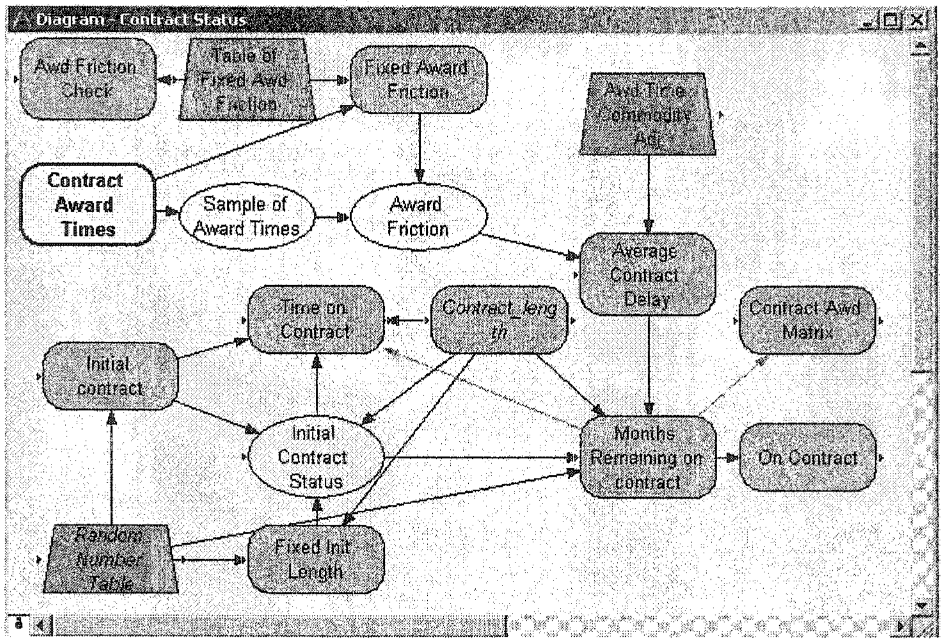
[168] An example of how to conduct a supply segmentation and some of the benefits of segmenting purchases by category can be found in: Kraljic, Peter, "Purchasing Must Become Supply Management," *Harvard Business Review*, September-October 1983.

[169] Delta airlines claims that approximately 60% of all maintenance actions are unplanned, and that this statistic is common for the industry. An industry with a large percentage of unplanned demands will have a larger percentage of demands for parts without contracts in place. Brown, Patricia, "Getting Inventory in Order," *Overhaul & Maintenance*, April 2003, pp. 32-40.

[170] In conversations with ALC personnel, this methodology is felt to accurately reflect the current practices of the Air Force where many contracts are allowed to lapse either through a longer than anticipated re-award process or a lack of manpower to ensure parts with infrequent demands are kept on contract. With the use of more reactive IPTs and contract award strategies, this could change necessitating a revision of this model parameter. Additionally, as the Air Force completes their segmentation analysis the parts could be grouped into different categories and different award times used for each category. Each of these modifications is left to future research efforts.

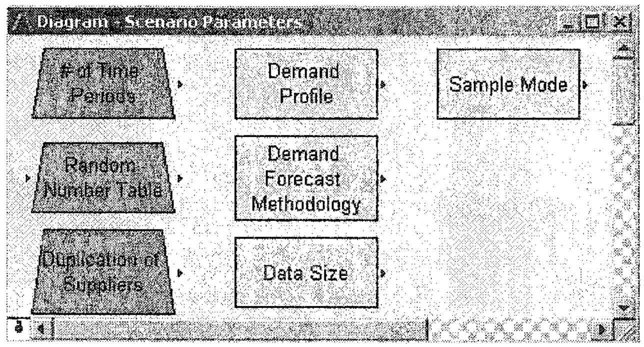
Figure 60: Contract Status Module



Scenario Parameters

As seen in Figure 61, the final module in the working model contains several nodes of system data needed for the model to operate correctly. The values of these nodes are set by the user through the system values sub-module of the interface module (shown in Figure 50). These values determine not only how many time periods the model computes and how many of the parts are included in the analysis (up to the number of parts included in the data set), but which demand profile and demand forecasting methodology are used by the model to generate demands and forecast the number of parts to order based on historical demands. The final two nodes in this sub-module allow the model user to run the model with a fixed table of random numbers (provided in this sub-module) or to run the model in a "random" sample mode where the demands are randomly selected for each part over a number of runs and the mean result of these runs computed for each outcome measure. The ability to run the model in a stochastic mode ensures the results are not sensitive to the particular set of "random" failures generated by a single model run but require additional computational resources limiting the ability to use this feature when conducting the exploratory analysis.

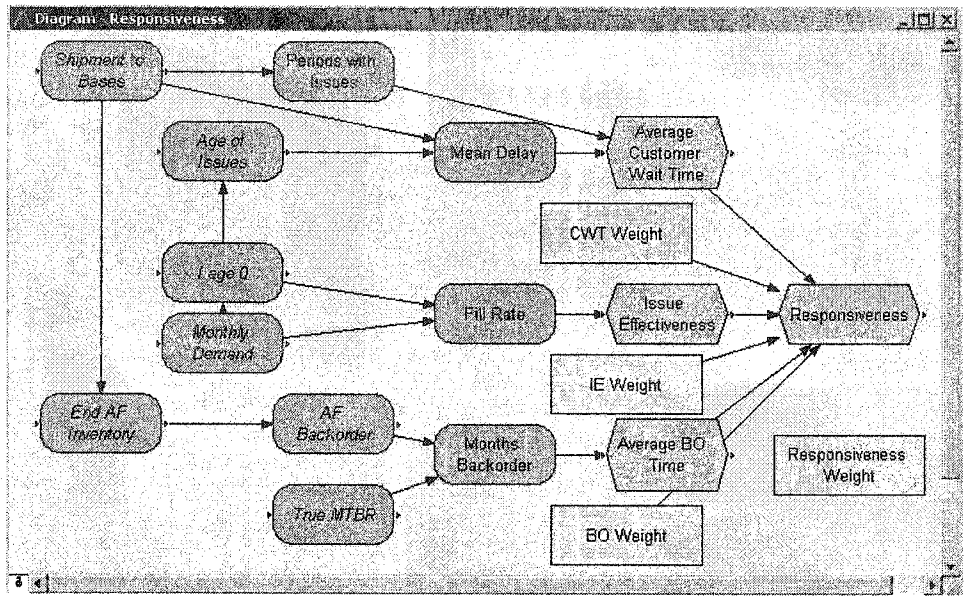
Figure 61: Scenario parameters Module



Output Measures

The final sets of modules in the PSM model contain the nodes and links needed to collect and report on the performance of the PSM process being modeled. These seven sub-modules, seen in Figure 53, represent each of the outcome measures under the broad categories of performance improvement and cost reduction are listed in Figure 11, of Chapter 4. To illustrate the design of these measures, Figure 62 provides a copy of the responsiveness sub-module. By separating the output measures into their own sub-module, the individual policy levers and model nodes used to derive each individual measure can be clearly seen. Analytica facilitates this modular construction by allowing aliases (duplicates) of key nodes to be placed in these modules, despite the fact that they are actually part of another portion of the model. These aliases are identified by the use of italics in the node title. For example, in Figure 62 the node representing the "Shipment to Bases" is actually part of the demand module but serves as an input into the mean delay calculation in the responsiveness module. By including a copy of the shipment to bases node in the responsiveness module, it is easy to visually see all of the key components used to construct the customer wait time metric in one location.

Figure 62: Responsiveness Sub-Module



An example of a cost measure, the personnel cost sub-module is shown in Figure 63. This sub-module explicitly captures the indirect personnel costs incurred by the Air Force to operate and support the PSM process. Figure 64 also highlights how sub-modules can be used to clarify the design of each individual metric within an output measures. In this case, each metric is given it own sub-module highlighting those factors that contribute to the number of employees required for each task.

Figure 63: Personnel Cost Sub-Module

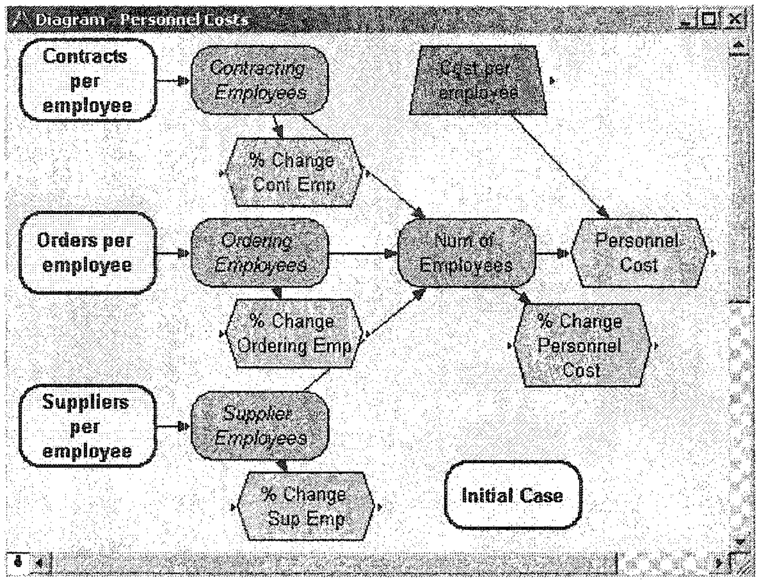
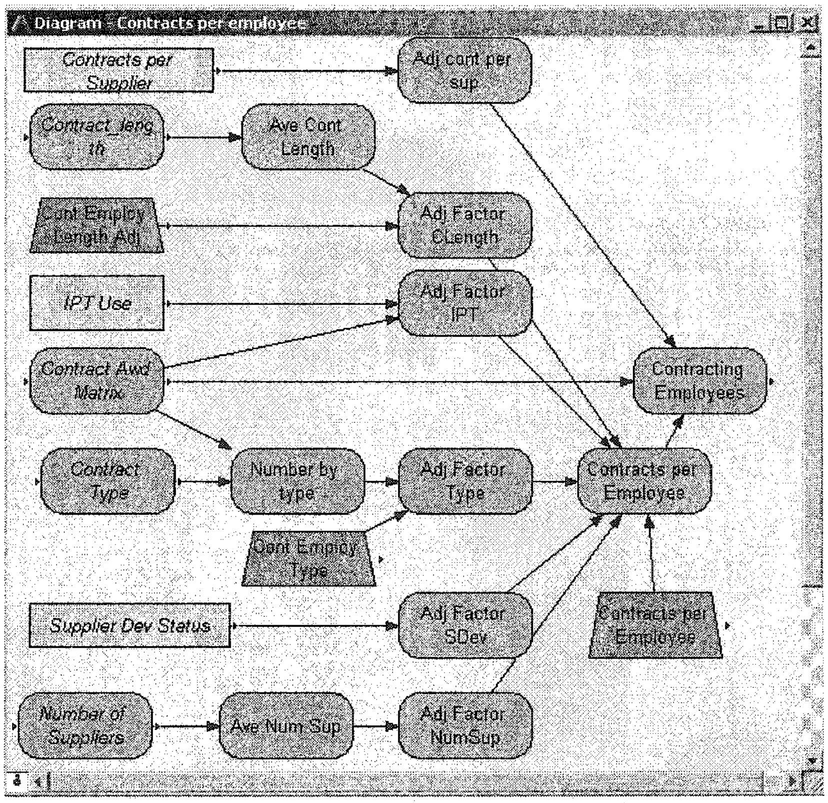


Figure 64: Contracts per Employee Sub-Module



Additional discussion regarding the design of each individual outcome measure is provided in Chapter 4.

B. Sources of Data

This appendix describes the data collection and preparation process used to generate the source data used for the PSM model. In general, the Air Force collects a vast quantity of data on what goods and services are purchased and from whom they are purchased. This includes historical demand information as well as data regarding the contract award process and performance of various suppliers. The data files used in this analysis also supported the F100 demonstration project at the Oklahoma City Air Logistics Center (OC-ALC). Many of these data files, available from various organizations within the Air Force, are collected and stored by RAND in its data facility. However, the raw data required extensive manipulation before it could be used to populate a model of the PSM process.

The preparation of the raw data for use in the Analytica model entailed three basic steps.

1. Selecting the list of parts to include in the model.

2. Collecting additional data elements regarding the characteristics of these parts, to include reliability, cost, and source of supply information.

3. Transferring the data into the model.

1. Parts List Selection

The decision to use the F100 engine as a demonstration of how the policy levers of PSM can improve performance was made by Air Force leaders in the January of 2002.[171] The master list of parts to be considered as potential candidates for inclusion in this analysis consists of all primary National Item Identification Numbers (NIINs) that have been purchased by the ALC to support the operation of the F100 jet engine.[172] By limiting the analysis to this parts

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[171] The decision was made jointly by MGen Saunders (AF/ILS), BGen Mansfield (AF/Il-I), and Mr. Robert Connor, Executive Director of OC-ALC during a meeting January 25, 2002, Reese, David L., "Recap of 25 Jan PSM Discussions at OC-ALC," email to PSM team, January 28, 2002.

[172] While parts are usually referenced by their National Stock Number (NSN), the NSN is actually composed of two elements, the Federal Stock Class (FSC) and the NIIN. As parts are occasionally moved from one FSC to another, the potential exists for the same part to have been purchased in the past using two different NSNs (having the same NIIN but different FSCs). To avoid this duplication, parts are sorted and analyzed by their NIIN in the development of the F100 database

(NIINs) list, the findings of this study can be compared to the demonstration effort at the Oklahoma City ALC.

Overall, the F100 has over 23,000 parts in its bill of materials, but only a portion of these requires repair or replacement.[173] For this dissertation, a subset of the parts requiring replacement was needed that was not only a representative sample of the entire list, but for which information regarding their failure and procurement information could be obtained. Acquiring this sub-set entailed filtering the master list of candidate NIINs in two ways.

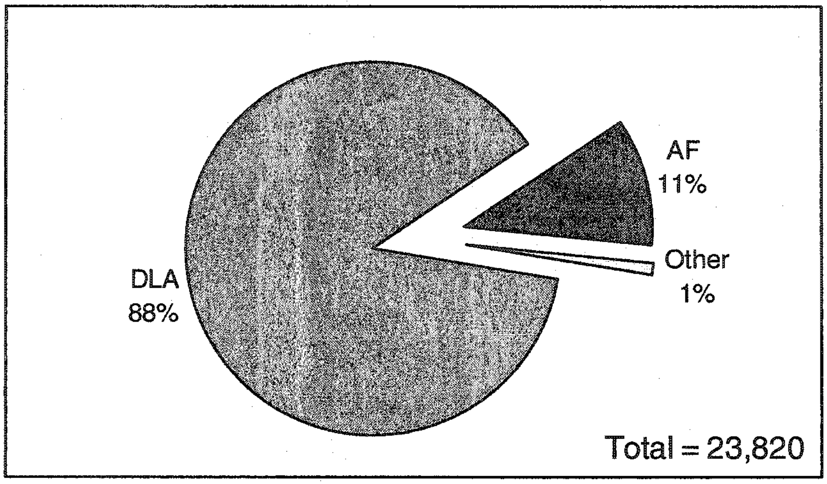
1. Limit data set to Air Force Managed Items: Within the DoD the sourcing of weapon system parts is currently divided between the individual services (Air Force, Army, etc.) and the Defense Logistics Agency (DLA). In the 1990s, DLA was given the responsibility to acquire all common parts as well as a majority of the service unique consumable parts (parts that are only replaced and never repaired). As shown in Figure 65 DLA manages a majority of the NIINs by count, but many of these are small common items used by other weapon systems.[174] Thus, the Air Force currently lacks control over the PSM practices for these parts. As one of the objectives of this dissertation is to produce a set of usable policy recommendations for the Air Force, DLA managed parts were excluded from consideration. Limiting the scope to only Air Force managed parts has the added advantage of ensuring a consistent source of data for all parts, because DLA data sets would not need to be combined with sources of Air Force data to get all of the required data elements.

used to populate the model. For other part lists whose items do not shift between FSCs, the analysis could be conducted at the NSN or NIIN level with similar results.

[173] The bill of materials for the F100 was developed by Oklahoma City and includes all parts that have been cataloged for all versions of the F100 engine. While not all of these parts have been purchased, they could potentially fail or need replacement if damaged during use. Source: Chenoweth, Mary, "Re: Data needed for my model," email to author, December 3, 2002.

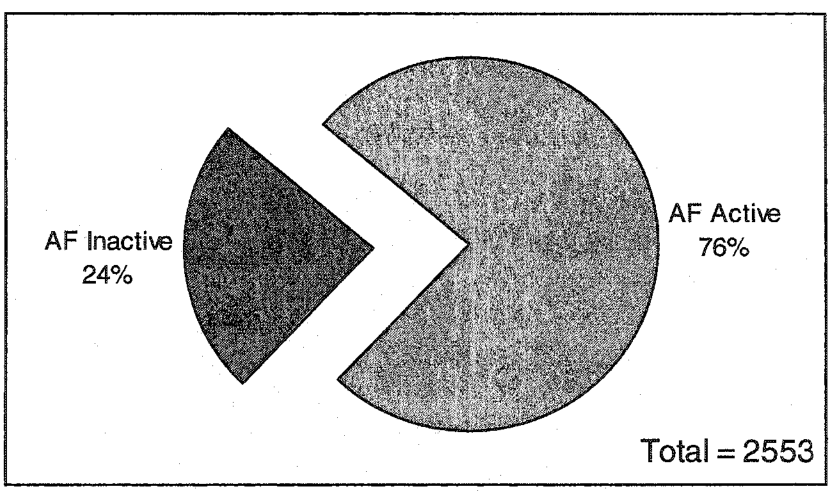
[174] DLA is responsible for a majority of the items on the F100, but the average price of the parts purchased by DLA is only $250 compared to an average price of $21,819 for Air Force managed parts.

Figure 65: Distribution of F100 Engine Parts



2. Limit data set to Active Parts: As with many products, a portion of the parts that make up an F100 engine rarely if ever fail and do not need replacement during the life of the system. For the Air Force managed F100 parts, 24% are considered inactive and are also excluded from this analysis as they are unaffected by changes in the procedures used to source spare parts (Figure 66).

Figure 66: Air Force Managed Parts



This filtering reduced the number of potential parts for inclusion in the study to a list of 1940 potential parts provided by Oklahoma City ALC containing a current list of parts managed by the Air Force.[175] After reviewing

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[175] This list of NIINs was initially compiled by RAND in support of the F100 demonstration project, and was reviewed and edited as required by personnel from the Oklahoma City ALC (AF

this list of parts, five additional exclusions were warranted to ensure the parts selected were a representative sample of parts purchased for the F100 engine.

1. Non-engine items: While identified as F100 parts, several categories of parts, containing 46 NIINs, were clearly not engine parts but support items not directly associated with the engine itself.[176] These were excluded to ensure the parts contained in the model were similar in their use and source of supply.

2. Kits: Some part numbers actually represent a kit of parts used together. A majority of these kits represents modifications or upgrades that only occur once in the lifetime of an engine. Consequently, because they are not part of the routine maintenance of the engine these items (134 NIINs) were excluded from this analysis.

3. Local part numbers: One NIIN was excluded because it used a locally assigned part number, which indicates that the part has not been formally cataloged. This could be a part that was not initially expected to fail, or an item that is only needed once and not part of the "normal" set of parts purchased for the F100. As a temporary part number, the quality of the information about this part is unknown making it unsuitable to include in an input into long-term policy recommendations.

4. Limit to master part numbers: Because there are five different versions of the F100 engine[177] and multiple versions of a particular part (different software or material) different part numbers can be assigned to items with the same form, fit, and function. This is due to slightly different configurations that make the two parts unique but in many cases interchangeable, or the same part can be coded in two different Federal Supply Classification codes (FSCs). These parts are considered unique, but interchangeable, and share a preferred "master" part number. For the purpose of this analysis, only master NIINs identifying parts with a unique form, fit, or function are included, and interchangeable parts are grouped under the master part number.

5. Parts with requisition history: While the listing of parts supplied by the ALC includes all actively purchased parts on the F100 engine, some of these parts may be repaired instead of purchased new from suppliers. Repaired parts, while of interest to the ALC when projecting the workload associated with

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[176] These include hand tools, storage containers, and signs.

[177] The variations of the F100 engine are the PW-F100-100, PW-F100-200, PW-F100-220, PW-F100-220e, and the PW-F100-229.

supporting F100 engine operations, have qualitatively different costs and lead times than the procurement of new parts. As they have different costs and cycle times, repairs are excluded from this analysis, which focuses solely on the purchase of replacement spares. Analysis of a four-year history of F100 part requisitions (FY99-02) determined the demand for parts from outside suppliers. As a result, an additional 380 NIINs were excluded from consideration that were not requisitioned during that time period.[178]

The remaining 1,245 NIINs represent the pool of potential Air Force managed parts for inclusion in this study. They are all active F100 parts that may be purchased to support operations in any given month. Due to computational limitations within Analytica, and to limit the data collection efforts, the attributes needed to populate the PSM model are collected from a random sample of 10% of the candidate NIINs in this pool of parts. This sampling produced a list of 123 NIINs to include in the model (See Table K for a summary of the selection process).

Table K: Summary of Part Selection Process

Air Force Managed Parts			1940
Less	-Non-engine Categories	46	
	-Local NIINs	1	
	-Kits	134	
	-Common master NIIN	134	
	-No requisitions	380	
Remaining parts under consideration			1245
10% random sample for model			123

2. Collection of Additional Data Elements

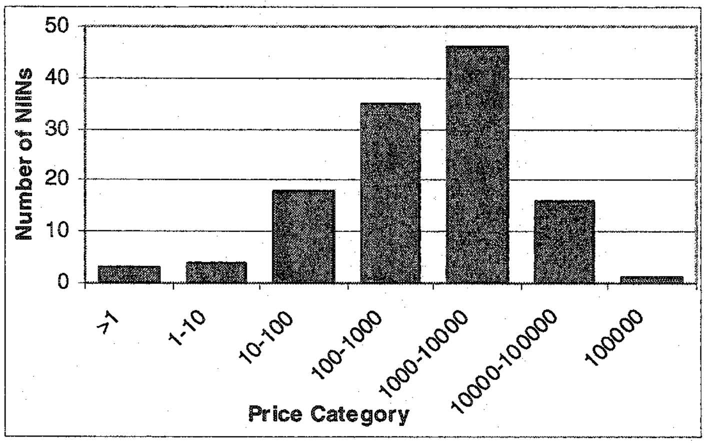
For each part selected to be included in data set used to test the PSM model, several additional data elements are required. Each of the data elements is discussed below, to include identifying the source of the data and the range of values for each element in the sample.

[178] Oklahoma City ALC provided the past four year's of requisition history to RAND. A summary file was provided for use in this study by, Chenoweth, Mary, "AF and DLA requisitions," email to author, February 17, 2003.

Standard Unit Price

Standard Unit Price represents the price paid by the MAJCOM customer, in dollars, for the part to include first destination transportation. This data element was provided by Oklahoma City ALC as part of their master parts list.[179] This price includes all contractor incurred overhead and indirect charges, but excludes the internal Air Force costs associated with procuring, managing, and distributing the part. Within the sample data set, the average part cost was $10,384 with a minimum and maximum cost of $0.70 and $524,388 respectively. Figure 67 contains a chart describing the distribution of standard unit prices for all Air Force managed F100 parts included in the sample.

Figure 67: Distribution of Unit Price (Sample Data)



Mean Time Between Requirement (MTBR)

In order to simulate the number of parts demanded each month, the frequency of demands placed on the supply base or MTBR was derived. Unlike traditional measures of failure rates, this model focuses on the ordering of parts from suppliers rather than the actual demand for parts from the operating locations. The actual quantity ordered by the Oklahoma City ALC for each NIIN over the past four fiscal years was used to compute the average demand rate.[180]

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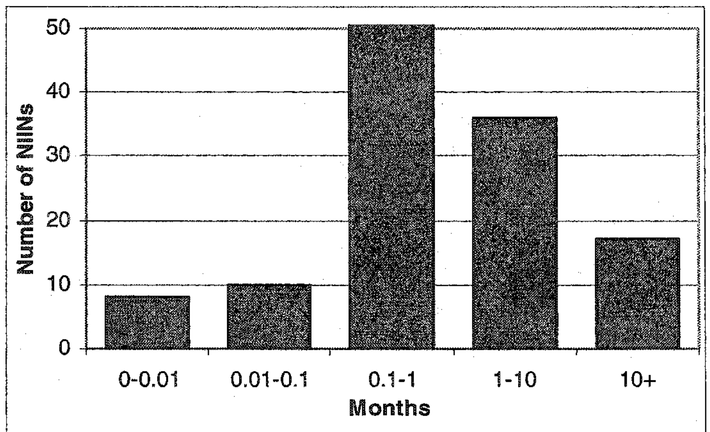
[179] AF F100 nsns (Master Data File).xls provided by: Jones, Dewayne, "Re: Inflation Factors," email to Mary Chenoweth, RAND Analyst, March 14, 2003.

[180] Oklahoma City ALC provided the past four years of requisition history to RAND. These requisitions could either be from an existing contract if one was in place at the time the demand for a replacement part occurred, or from a new contract awarded after the demand occurred. In the current data set, it is not possible to distinguish between the two types of orders. A summary file

For the sample of NIINs, the average time between orders was 5.22 months (or stated another way a part was ordered every 157 days) with a minimum and maximum rate of a part every 1.7 hours to one every 48 months respectively. Figure 68 provides a chart describing the distribution of the requisition rates.

Figure 68: MTBR Distribution (Sample Data)



Commodity Group

Within the DoD, Federal Stock Classifications group similar parts. However, with over 22 different FSCs represented in the sample of 123 parts, a more generic grouping methodology is needed to combine parts with a similar source of supply. For example, within the sample are three FSCs containing electrical components and two FSCs for different types of bearings. Combining similar FSCs into commodity groups not only simplifies the analysis, but it creates categories that are large enough not to be influenced by a single part (7 of the FSCs had only 1 part in the sample). Within the current data set, similar FSCs were combined into seven individual commodity groupings.[181] The distribution of parts by commodity group is represented in Table L.

was provided for use in this study. Source: Chenoweth, Mary, "AF and DLA requisitions," email to author, February 17, 2003.

[181] This method of grouping parts is similar to the one actually used by Oklahoma City ALC. However, as the ALC is concerned with all parts on the F100 and must make specific sourcing decisions, they have elected to further subdivide engine components by type of part and material used during production (i.e. titanium shafts or ceramic blades).

Table L: NIIN Distribution by Commodity Group

Commodity Group	NIIN Count
Engine Components	47
Engine Parts	20
Tubes/Valves	21
Bearings	5
Electrical	5
Hardware	20
Other	5

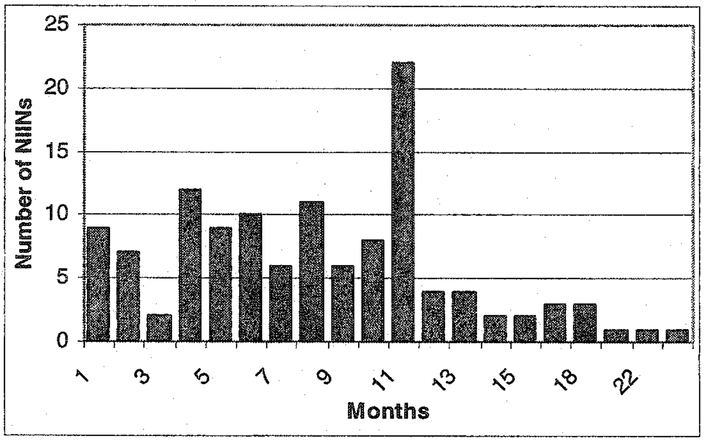
Production Lead Time (PLT)

Production Lead Time represents the amount of time required by the supplier to produce the part once they receive the order.[182] For common parts that the supplier maintains in their inventory, this is simply the amount of time required to process the order. However, for complex, unique items this may include a significant amount of time to source needed materials from second tier suppliers, to fabricate components, or to assemble the item. OC-ALC included this data element in their master parts list.[183] For the sample of NIINs, this value varies from 1 to 27 months with a mean value of 8.3 months (see Figure 69).

182 In Joint Publication 1-02, dated January 9, 2003, production lead time is defined as, "The time interval between the placement of a contract and receipt into the supply system of materiel purchased."

183 AF F100 nsns (Master Data File).xls provided by: Jones, Dewayne, "Re: Inflation Factors," email to Mary Chenoweth, RAND Analyst, March 14, 2003.

Figure 69: PLT Distribution (Sample Data)



Administrative Lead Time (ALT)

This parameter represents the amount of time required to process the requirement for a part and send a requisition to the supplier.[184] For catalog parts on a contract, this is simply the act of ensuring that sufficient funding is available and placing the order. However, for parts that require tailored procurement activities, this includes the effort associated with identifying prospective suppliers, developing the request for proposals, receiving solicitations, and selecting and negotiating the actual purchase with the supplier. The ALC provided this data element as part of their master parts list.[185] For the sample of NIINs, this value varies from 0 to 9 months with a mean value of 2.77 months (see Figure 70). Of the 123 NIINs included in the sample, three NIINs were reporting an ALT of zero months. To prevent computation difficulties these values were increased to 1 day.

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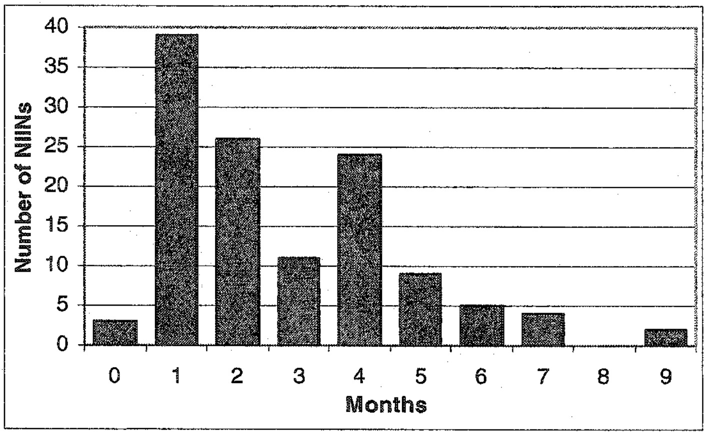
[184] In Joint Publication 1-02, dated January 9, 2003, administrative lead time is defined as, "The interval between the initiation of procurement action and letting of contract or placing of order."

[185] AF F100 nsns (Master Data File).xls provided by: Jones, Dewayne, "Re: Inflation Factors," email to Mary Chenoweth, RAND Analyst, March 14, 2003.

Figure 70: ALT Distribution (Sample Data)



Delivery Time

As mentioned earlier, the Analytica model of the PSM system focuses on the delivery of parts from suppliers to the Air Force. The delivery time required for the suppliers to pack and ship the parts to the Air Force is needed. However, this information is not tracked in any Air Force database. Contractual language requires the delivery of each item by a certain date, which includes not only shipping time but also the suppliers PLT and internal administrative time needed to process the order. The Logistics Response Time (LRT) was used to serve as a proxy for the delivery time. LRT represents the time required to ship items within the DoD from the point of origin (depot or supplier) to the base requesting the part. It is assumed that, in general, the suppliers would use similar shipping methods (i.e. surface or air) and thus would have similar delivery times.

The logistics response time for each NIIN was sourced from the Logistics Metrics Analysis Report System. This data was compiled by month within RAND,[186] and for this project the average LRT for a twelve-month period (Oct 01 - Sep 02) was computed and used to represent the time required for suppliers to deliver parts to the Air Force. To ensure the times were comparable to the time a supplier would require to deliver a part to the ALC, this computation included only those shipments to an Air Force base located within the continental United States; excluding shipments to overseas locations and to other DoD agencies.

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186 Boren, Pat, Research Programmer, RAND Corporation, interview with the author, Santa Monica, CA, February 17, 2003.

Also excluded were atypical deliveries that included backorder delays or shipments directly from a supplier to a base. This resulted in a data set containing an average of just about five shipments per part.

When the LRT information was compiled by NIIN, only 64 of the 123 NIINs in the sample had a delivery in the 12-month period included in the analysis. This indicates that either many of these parts are not ordered frequently, or that they are not shipped between Air Force organizations.[187] To estimate representative LRTs for parts without a delivery, a bootstrapping procedure was used, where delivery information for a similar part was used in lieu of actual data for a particular NIIN. Parts with LRT information that were similar to those in the sample that were missing LRT information were manually selected from the master list of all 1940 Air Force F100 parts. This selection involved choosing parts with a similar description and price for which there was sufficient LRT data.[188] Comparing the average delivery time of those parts in the sample with LRT data and those whose LRT data was estimated to the overall average LRT times for all F100 parts, we find no statistically significant difference in their distribution (see Table M).

Table M: Delivery Time Comparison by Source

Category	Number of parts	Mean	Standard Deviation
Sample with LRT Data	64	5.87	4.56
Sample with Estimated Data	59	5.57	5.17
Entire F100 part population	1940	5.53	4.97

As a final check to ensure that the parts with LRT data are not different in some systematic manner, the average price of parts with and without LRT data was compared. As seen in Table N, there is no statistical difference in the price of these two sets of parts. While not conclusive evidence that all LRT values used in the model represent an unbiased estimate of the amount of time required for suppliers to deliver parts to the Air Force, these tests find no evidence to the contrary.

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[187] While only 17 of the 123 NIINs had an average time between requisitions of over 10 months, LRT data only tracks shipments from the Depots to the bases. Many of the parts purchased to support the F100 are used only at the Depot for repairs of engines or engine modules. Thus, having delivery information for only half the parts purchased from suppliers is not unexpected.

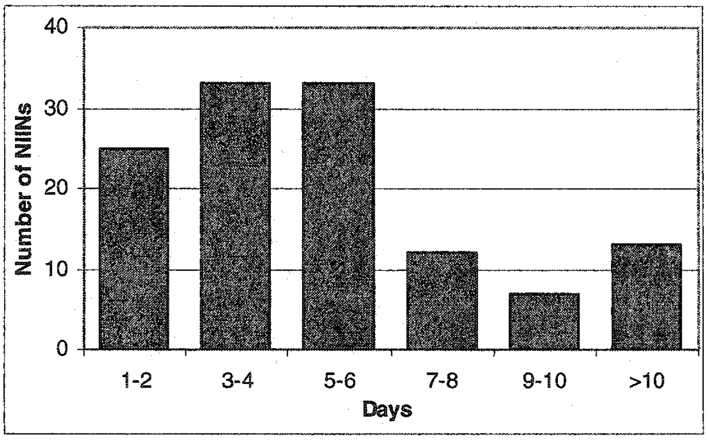
[188] A more formal discussion regarding the use of bootstrapping to estimate mission data and some of the statistical implications of this technique can be found in: Efron, Bradley, "Missing Data, Imputation, and the Bootstrap," *Journal of the American Statistical Association*, Volume 89, Issue 426, June 1994, pp. 463-475.

Table N: Price Comparison (LRT vs. No LRT Data)

	Average Price	Standard Deviation	P Value
Parts without LRT	20,937	2,561	
Parts with LRT	23,083	4,307	
Difference	-2,146	4,728	0.65

The distribution of delivery times used in this sample range from 1 day to 31.5 days, with a mean value of 5.7 days. Figure 71 provides a distribution of these delivery times.

Figure 71: Delivery Time Distribution (Sample Data)



Contract Information

Data regarding nature of the relationship between the Air Force and suppliers for each part is needed to understand how changes to the PSM process will affect these relationships. Most DoD contract information is organized by contract number rather than NIIN. Therefore, acquiring information on the type of contract, contract length, and number of potential suppliers first required the determination of what contracts were used to source each part. Contract information can provide an understanding how these contractual relationships are structured. This data collection process required the merging of multiple databases as described below. Contract numbers were generated for each NIIN, and information was then secured regarding the structure of those contracts. This detailed information was consolidated and converted into data useable for the PSM model.

Consolidating Contract Information

Using a file provided by other RAND personnel working on the F100 PSM Demonstration project, each of the 1940 NIINs in the master database were linked to contract numbers used from Fiscal Year 1999 to Fiscal Year 2002.[189] This merge provided over 5000 contract numbers or an average of about 2.5 contracts per NIIN. For the 123 NIINs included in the PSM model, 91 had one or more contracts from which to gain the required information. The remaining 32 NIINs failed to match a contract number in the data provided. This failure could be a result of the fact that the contract used was awarded before Fiscal Year 1999, the NIIN was input incorrectly in the source data used to develop the file, or the part was requisitioned outside of the systems from which the NIIN/Contract Number file was developed.

To generate representative data for these parts, a bootstrapping procedure was used, where contract information from a similar part was used in lieu of an actual contract. This was done by manually selecting parts similar to those in the sample based upon the description of the part, its price, and production time, but missing contract information and then by selecting the most recent contract used to purchase a similar part.[190]

Once contract numbers were developed for all NIINs in the sample, these contract numbers were then merged with a data base containing all Air Force contracting transactions valued over $25,000 from Fiscal Year 1999 to Fiscal Year 2002.[191] This produced a file of 1,896 contracting actions (including both the original contract award and subsequent modifications to add additional items or adjusted contract terms and conditions) used to purchase the 123 parts in the past four fiscal years (Fiscal Years 1999-2002). A summary of this process linking NIINs to contracting actions is pictured in Figure 72, showing how each

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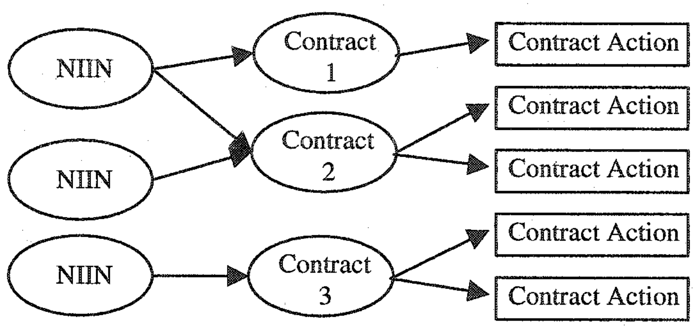
[189] f100_fy99t02.csv provided by: Chenoweth, Mary, "New post-award file," email to author, May 19, 2003.

[190] This procedure relies upon the fact that parts without contract would be sourced with a contract having similar attributes to those present in the database. As the policies and procedures used to source parts at OC-ALC have not changed significantly prior to this periods, those parts using older contracts awarded prior to FY 1999 should have been sourced from contracts with similar characteristics.

[191] The raw data used to develop this contract database is extracted from the contract Action Data file containing information extracted from all Individual Contracting Action Reports (DD Form 350) over $25,000. This raw data is available online at U.S. Department of Defense, Directorate for Information Operations and Reports, Procurement Guidance and Data, 2003, http://web1.whs.osd.mil/peidhome/guide/procoper.htm (as of June 6, 2003). RAND, as part of an earlier project to determine what and from whom the Air Force purchases goods and services, analyzed this raw data and produced a consolidated file of all Air Force contracts for each of the past several fiscal years. This dissertation used these validated files to obtain contract attributes for each contract used to purchase the NIINs included in the PSM model.

individual NIIN could be sourced from one or more contracts and each contract can in turn have multiple contracting actions. From this composite file of part attributes and contract data, information the contract type, length, and number of suppliers was derived.

Figure 72: Link Between NIINs and Contract Actions



Contract Type

In general, the optimal type of contract depends upon the nature of the items purchased and the certainty with which the requirement is known.[192] Thus, there is not a "best" type of contract for all items. Rather, some items are best suited for a Firm Fixed Price (FFP) type of contract that allows the supplier to perform as they choose to meet the requirements of the buyer, while other items are best suited to a Cost plus contract where the exact cost of the item is not finalized until after production and/or delivery. With prices based on supplier's costs, cost contracts require that costs be reported by the supplier and audited by the buyer before finalizing the payment for an order, which increases the cost of monitoring both contracts and orders. The F100 engine has been in operation since 1972, consequently the parts in this model all use a Firm Fixed Contract.[193] While this limits some of the computational permutations within the model, it is reflective of weapon system support environments, which are dominated by FFP contracts.[194]

Contract Length

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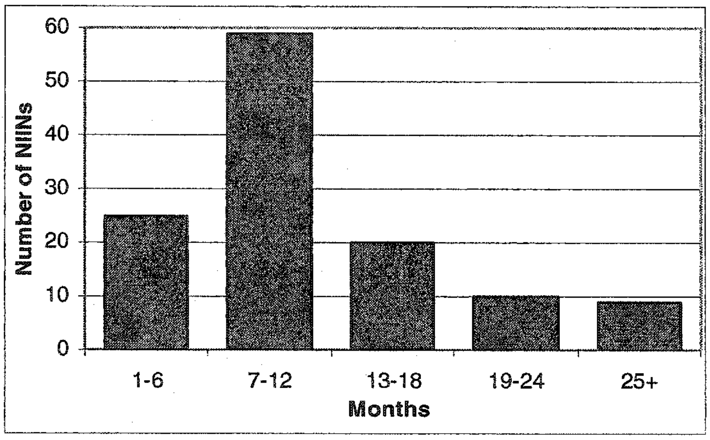
[192] Bajari, Patrick and Steven Tadelis, "Incentives Versus Transaction Costs: A Theory of Procurement Contracts," *RAND Journal of Economics*, Vol. 32, No. 3, Autumn 2001, pp. 387-407.

[193] For a historical account of the F100 engine see: Pratt & Whitney, "Pratt & Whitney Through the Century," Online at: http://www.flight100.org/history/pratt_whitney.html (as of June 9, 2003).

[194] According to the Federal Acquisition Regulation, "A firm-fixed-price contract, which best utilizes the basic profit motive of business enterprise, shall be used when the risk involved is minimal or can be predicted with an acceptable degree or certainty." Only when a reasonable basis for firm pricing does not exist should other contract types be considered. Federal Acquisition Regulation, *Subpart 16.103 – Negotiating Contact Type*, current through May 22, 2003. Online at http://www.arnet.gov/far/. (as of June 9, 2003).

The length of time a particular contract is in effect determines how often contracts must be renegotiated. While contract length is not explicitly stated on the DD350, this form contains the contract start and completion date, from which the contract length can be estimated. By taking the difference in these two dates and averaging them over the number of contracts for each NIIN an estimate of the contract length can be determined. This raw average (rounded up to an even number of months) was used for all but eight of the 123 NIINs. Two of the NIINs were missing either the start or the completion date and a default value of 1 year (12 months) was used for these parts. Additionally, six NIINs had one or more contracts in which the completion date of the contracting action occurred before the contract start date. It was assumed that these dates were recorded in error for these observations and they were excluded from the computation of the average contract length for these NIINs. Overall contracts ranged in length from 1 to 39 months with an average length of 12.1 months. A distribution of these values by length is provided in Figure 73.

Figure 73: Contract Length Distribution (Sample Data)



Supply Base

The final data element needed to populate the model of the PSM process is the number of potential suppliers (bidders) for each NIIN. Like contract length, this data is not an explicit part of the information contained in the DD350 database. However, several other data elements provide an indication of the competitiveness of the supply base for each NIIN and contract. The primary source of information used to determine the number of suppliers for each NIIN comes from the Acquisition Method/Acquisition Method Suffix Codes

(AMC/AMSC) codes provided in the master NIIN data file.[195] This code, provided for each NIIN, reflects the level of competition for each part as well as the information regarding the reason this procurement method was chosen. These codes represent the collective judgment of the ALC experts on the competitiveness of a spare part and is assigned prior to contract initiation. The codes apply only to the purchase of spares, not the repair of damaged parts. For example, a code of 3C indicates that the part should be procured directly from the manufacturer (represented by the 3 in the code) because the part required engineering source approval for all suppliers to maintain the quality of the part (represented by the C in the code). In addition to this provisioning information, the DD350 contains fields indicating the degree of competition used in soliciting the part and the number of offerors who bid on the requirement. Combining these two sources of data allowed the estimation of the number of suppliers using the decision rules outlined in Table O. The AMC and AMSC code served as the primary source of information regarding the range of potential suppliers (i.e. is the number of sources for the part restricted), with actual data from the DD350 database used to determine the actual number used in the PSM model.

Table O: Determining the Number of Suppliers

Number of Suppliers	AMC	AMSC	Level of Competition from DD 350
1	3-5	Any	Only one offeror and Other than full competition
2	3-5	Any	More than one offeror or Some competition
	1-2	Any	Only one offeror and Other than full competition
3	1-2	Any	More than one offeror or some competition
5	1-2	G	More than one offeror and Some competition

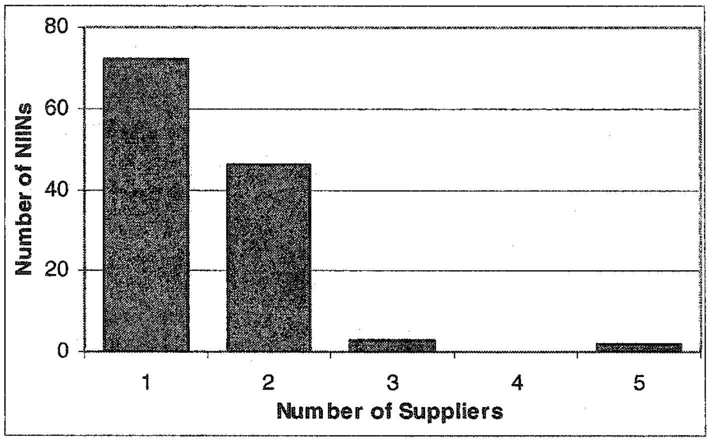
While the possible range in the number of suppliers extends from 1 to 5, due to the complex nature of jet engine parts, a majority of these parts (59% in the sample data) has only one source and must be purchased from the original equipment manufacturer.[196] The implications of so many sole source parts is

[195] For more information on the various Acquisition Method/Acquisition Method Suffix Codes see Tables 70 and 71 of DoD 4100.39-M, Volume 10.

[196] This is higher than the Air Force average of 31% of all contracts over $25,000 going to a sole source provider. Source: FY 02 Air Force-wide DD350 data.

discussed in the findings portions of this dissertation. This results in an average of only 1.5 suppliers per part, with the actual distribution in the number of suppliers shown in Figure 74.

Figure 74: Number of Suppliers (Sample Data)



3. Transfer of Data Into the Model

As most of the data consolidation and preparation was completed using Microsoft Excel, the actual transfer of the data into Analytica was straightforward. Both Excel and Analytica are Windows based software packages; allowing data to be copied and pasted between them. However, before the transfer, the data was checked to ensure it used the proper scale (i.e. days or months) and was in the correct format (i.e. numbers vice text or number per month vice number per year). During this review, summary statistics such as the first and last value of each data column and the average value were noted. After copying the data into Analytica, it was reviewed to ensure it had been transferred correctly. The values of the summary statistics before and after the transfer were compared to ensure the data was imported into the model correctly. Having validated that the data in the model was current and complete, the exploratory analysis process could begin.

C. Policy Levers

This appendix contains a more detailed and technical discussion of how each of the individual policy levers affects the performance of the PSM process. Many of these relationships have simple linear or quadratic functional forms. These forms were determined by examining the economic and business literature to capture pertinent concepts (such as the effect of creating a monopoly), and looking at case studies where changes were made to determine if the effects are replicable. These initial effects were then reviewed and modified as necessary, after interviews with Air Force and academic personnel knowledgeable in both the current practices of the Air Force and commercial PSM practices as well as how change to PSM policy levers might alter those practices.[197] This combination of theoretical and practical sources of information ensures that the effects captured in the model reflect actual business practices but are also grounded in economic theory. Where differences occur, the model was tailored to reflect Air Force operations, which, due to political and legislative constraints, may operate differently than a traditional open market.[198] These differences are noted in the assumptions regarding the effect of each policy lever.

These changes represent those effects that are likely to occur in most cases due to the basic nature of the process, but may or may not be all-inclusive or representative of all parts included in the analysis. For each policy lever, a number of effects will be presented to include bullets justifying why the effect is thought to occur as well as a brief discussion of how the effect was modeled.[199] As mentioned in the introductory chapter, before adopting the results of this

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[197] As part of the implementation of PSM at the Oklahoma City ALC, a PSCM implementation office has been formed and staffed with experienced Air Force personnel from the areas of contracting, supply management and logistics. They are tasked with learning how PSM can improve current practices and implementing those changes thought to improve current operations. Thus, they are knowledgeable both on current efforts as well has how those efforts might be affected by changes to current practices.

[198] For example, the government has the ability to require firms provide certified cost and pricing data to support pricing actions when sufficient competition is not present in the market place. While this will not completely mitigate monopolistic efforts of the supplier, it restricts their ability to charge prices that exceed a fair and reasonable profit margin.

[199] The nature of the relationship between the policy levers and the components of the PSM model was determined either through evidence from the business literature or discussions with functional experts regarding the direction and rate of change that should occur when each policy lever is adjusted. These functional forms were then parameterized either using information relating to the degree of change found in the business literature, from input from functional experts, or based on the author's estimation of the degree of change possible. In all cases, these values were chosen to ensure that no individual policy lever would in all cases improve or reduce cost and performance.

model, further analysis is required to ensure all the assumptions are consistent with the business environment under consideration. This includes further research to validate the functional form and parameterization of each of these effects.

Number of Suppliers

This parameter reflects the number of suppliers that the Air Force considers as part of the "bidding pool" for a given requirement. This number represents the number of potential suppliers the Air Force attempts to have on contract for each part. This number is limited by the number of bidders in the market place (i.e. there is only one possible source of a sole source part) but it can be further limited by the decision to restrict business to a smaller set of select or "preferred" suppliers.

The model as designed assumes that changes in the number of suppliers for a particular company (i.e. the Air Force) does not change the number of suppliers in the market place. In the case of the jet engine parts market, this appears reasonable because commercial airlines are a large percentage of the jet engine component market. Thus, for the suppliers of F100 parts, it is assumed that the Air Force cannot influence the number of suppliers in the market place. That is, the sourcing decisions of the Air Force will not create additional sources of supply, nor will cause current suppliers to leave the market.

While traditional economic theory suggests that increased competition will lower prices and improve quality, this assumes that the Air Force can actually affect the structure of the market place. Modern transaction cost economics recognizes that while more suppliers reduces the prevalence of monopolistic forces; economies of scale can make markets with fewer participants more efficient.[200] In the long run, increased competition can in some cases actually increase total cost and reduce quality.[201] Particularly in the jet engine market where the Air Force is a small percentage of the overall market, any effect the Air Force has on the market place is likely to be small. However, the Air Force can choose to limit the number of suppliers it does business with within the jet engine market, increasing it's leverage and improving the responsiveness of its

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[200] Williamson, Oliver E., *The Economic Institutions of Capitalism*, New York: The Free Press, 1985, p. 40.

[201] Hahn, Chan K., Hyoo H. Kim, and Jong S. Kim, "Costs of Competition: Implications for Purchasing Strategy," *Journal of Purchasing and Materials Management*, Fall 1986, pp. 2-7.

chosen suppliers. This increased buyer power can result in lower prices, and better performance.[202]

In general, more suppliers will...[203]

1. Increase the number of delivery orders needed to source a given number of parts.

    – This increase assumes that you will distribute the order for a given number of a particular amongst the individual suppliers. This will increase the number of orders processed, increasing total order costs.

    – Having more orders for each month's requirement will also make the processing of these orders harder (more suppliers to coordinate with, ensure all contractual limitations are met, work to balance orders, etc.) In the model this is represented by decreasing in the number of orders each employee equivalent can process (orders/employee) as it is more difficult to prepare and review these order packages (coordinate the order) than to just cut an order with a single vendor.

    – The model assumes that orders are equally distributed to all suppliers. Each supplier added to (or removed from) the bidding pool will add (or remove) one delivery order during months where the number of parts ordered exceed the number of available suppliers.

2. Increase cost of administering contracts.

    – As with orders, having multiple suppliers requires the coordination between the contracting officers awarding these contracts to balance terms and conditions and may result in more protests of real or perceived inequalities. More suppliers will increase the total time required to administer and monitor the contracts for a particular part.

    – Increasing the number of suppliers increases contract administration costs at an increasing rate modeled using a quadratic functional form.

3. Increase the percentage of defective parts.

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[202] Cox, Andrew., Joe Sanderson, and Glyn Watson, "Supply Chains and Power Regimes: Toward an Analytic Framework for Managing Extended Networks of Buyer and Supplier Relationships," *The Journal of Supply Chain Management*, Spring 2001, pp. 28-35.

[203] For a detailed case study regarding the benefits of reducing the supply base see, Ogden, Jeff, "Supply Base Reduction Within Supply Base Reduction," *Practix*, Volume 6, January 2003.

- With a larger suppler base and the same number of inspectors, you have less time to work with each supplier.[204] This will result in more variance in the quality of the parts received, increasing the defect rate. Conversely, limiting the supply base allows the Air Force to select those suppliers that consistently provide high quality parts, reducing the defect rate.[205] With fewer suppliers, the buyer and supplier form more of a partnership where needs are better understood and quality improves.[206]

- As the worst performing suppliers are the first to be removed from the supply base, this model assumes that decreasing the number of suppliers decreases the number of defects at a decreasing rate, modeled using a quadratic functional form. Based on discussions with personnel from the Okalhoma City ALC, it is assumed that with an 80% reduction in the number of suppliers, the percentage of parts with defects can be reduced 30%.

4. Increase the number of supplier development interactions making supplier development more expensive.[207]

   - An active supplier development program requires Air Force personnel to work with each supplier to improve their practices. More suppliers to work with will increase the total (not per supplier) cost of conducting a supplier development program.

   - The model assumes that supplier development efforts are spread evenly across all suppliers. Thus, supplier development costs are linearly related to the number of suppliers.

5. Alter part cost (effect depends upon the competitiveness of the market).

   - Unlike other changes as a result of adjustments in the supply base that depend upon the total number of suppliers with which the Air Force

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[204] Ogden, Jeff, "Supply Base Reduction Within Supply Base Reduction," *Practix*, Volume 6, January 2003, p.6.

[205] One Oklahoma City ALC engineer surmises that upwards of 75% of the defects could be avoided just by limiting the supply base to suppliers who have demonstrated the ability to provide quality parts.

[206] Graham, T. Scott, Patricia J. Daugherty, and William N. Dudley, "The Long-Term Strategic Impact of Purchasing Partnerships," *International Journal of Purchasing and Materials Management*, Fall 1994, pp. 13-18.

[207] The need to eliminate problems suppliers and focus supplier development efforts on the remaining suppliers was stressed by Boeing's vice president of quality in, Trent, Robert J., "Applying TQM to SCM," *Supply Chain Management Review*, May/June 2001, pp. 70-78.

does business, pricing is dependent upon the nature of the market (number of possible suppliers) for each individual item.

- In a single (sole) source environment, you cannot alter the supply base so adjusting the number of suppliers is not possible.
- In markets with limited competition increasing the supply base decreases monopoly forces and can result in reduced part costs.[208]
- In competitive markets increasing the number of suppliers that the Air Force does business with gives each vendor a smaller share of the Air Force's business (and decreases the importance of the Air Force to them as a customer). This should result in poorer contract terms and higher prices.[209]

– The model assumes that until there are three suppliers for each part, increasing the number of suppliers will decrease prices (less monopoly power) at a decreasing rate. Additional suppliers beyond three are assumed to increase prices at a decreasing rate as the Air Force's leverage with suppliers is reduced. All price changes were modeled using a quadratic functional form.

Number of Contracts per Supplier

This parameter reflects the number of individual contracts you have with each supplier. It assumes that you have more than one NIIN with each supplier (in general) or multiple contracts for the same part, and have the option of awarding individual contracts for each NIIN or grouping several NIINs into one contract.

Fewer contracts per supplier will…

1. Increase individual contract award time.

   – Larger contracts, with multiple parts on each contract, take more time to award increasing the time required to award each individual contract. This is because contracts with a higher value receive additional scrutiny

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[208] Oklahoma City ALC personnel indicated that within the Air Force the government's use of cost and pricing data to ensure a "fair and reasonable" price mitigates some but not all of the threat of monopolistic activities.

[209] Cox, Andrew., Joe Sanderson, and Glyn Watson, "Supply Chains and Power Regimes: Toward an Analytic Framework for Managing Extended Networks of Buyer and Supplier Relationships," *The Journal of Supply Chain Management*, Spring 2001, pp. 28-35.

and are reviewed by higher levels of management. When awarding a contract with multiple line items, delays in individual line items delay the entire contract.

- Reducing the number of contracts per supplier inversely affects contract award times, as delays are caused not only by having additional items to negotiate but the price of all items must be coordinated. As most of the contract award time is spent structuring the basic document, the increase associated with adding additional parts is relatively minor with a 20% reduction in the number of contracts per supplier resulting in a 3% increase in average contract length.

2. Decrease the total cost of awarding contracts for all parts.

   - With fewer contracts to award, despite the increased unit cost of awarding one contract, the total cost of awarding contracts for all parts will be reduced.

   - The cost of awarding each contract is assumed to increase linearly with the reduction in the number of contacts per supplier, but with fewer contracts to award the average costs of awarding a contract for each individual part will be lower. As the number of contracts per supplier is not known for each part, it is assumed that, in general, a 20% reduction in the number of contracts per supplier will decrease the average contract award cost by about 4%.

3. Increase the ease of modifying a requirement (support quality).

   - Changing the requirements for a particular part when each part is on a separate contract requires the modification of that contract plus possibly a modification to another contract to free up resources to cover the increase (assuming a fixed budget). Larger contracts also result in fewer contracts per contracting officer allowing each contracting officer to spend more time monitoring a given contract. This increased monitoring is likely to improve contract performance and supplier responsiveness.[210]

   - The use of IPTs enhances this effect as you have more people working on the modifications. When you have many people trying to work together

[210] Oklahoma City ALC personnel felt this was particularly true for Air Force contracts as the amount of time currently spent monitoring contractual activities is largely compliance driven rather than seeking to improve the quality of the contractual relationship.

to modify multiple contracts then cross communication can be even more difficult to coordinate.

- Ease of modification is assumed to increase linearly with changes to the number of contracts per supplier, with a 20% reduction in the number of suppliers improving the ease of modifying contracts by 5%.

4. Reduce the effectiveness of using performance measures.

   - With more line items on a contract, performance measures become more difficult to define (particularly in the case of parts contracts) as performance over a large number of items will naturally regress to an average performance level.[211] This is true only for parts contacts (like those used to support the F100) in which all items are individual deliveries.[212] In a services contract, grouping all requirements into one large contract allows the supplier to have control over the entire process facilitating the alignment of incentives and the use of overall performance measures.[213]

   - The level of change in performance measures is reduced linearly with the number of contracts per supplier. For example, if the level of performance measures is doubled, and the number of contracts per supplier is reduced by 20%, the effective change in performance measures is reduced by 20% to a level of 1.8 times the baseline case. This reduction is highly dependant on the assumption that performance measures are used at the contract level and not placed on the delivery of individual parts.

5. Reduce the price paid for each item.

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[211] Having more items in each performance measure is the same as having a larger sample from the "random" distribution of performance (assuming that some factors that drive performance are independent of any systematic effort by management). For more information regarding averaging multiple samples to form an overall measure see: Moore, David S. and George P. McCabe, *Introduction to the Practice of Statistics*, New York : W.H. Freeman and Company, 1999, pp. 398-400.

[212] For this condition to occur, it is assumed that the performance measures are written at the contract level rather than having individual performance incentives for each individual contract line item. Traditionally, this is how the Air Force writes performance measures.

[213] RAND has identified the alignment of related items to improve buyer-oriented measurement as a benefit of bundling common purchased services. Baldwin, Laura H., Frank Camm, and Nancy Y. Moore, *Federal Contract Bundling: A Framework for Making and Justifying Decisions for Purchased Services*, Santa Monica, Calif.: RAND, MR-1224-AF, 2001, p. xiv.

- With larger consolidated contracts, volume discounts and increased buyer leverage will reduce the price paid for each item.[214,215]

- The price paid for each part is assumed linearly related to the number of suppliers, with a 50% reduction in the number of contracts per supplier resulting in a 6% reduction in price.

Supplier Development

This parameter measures the amount of personnel effort the Air Force puts into working with the suppliers to improve their processes and the interface between the two enterprises. This can range from none (working only through the contract and accepting the suppliers performance as they are currently structured) to an extensive partnership where the Air Force assists the suppliers in improving both the production process as well as revising their business and financial procedures to streamline and better integrate with the Air Force's systems. While the optimal level of investment in suppliers depends upon the nature of the market and the items being sourced, improving the link between buyers and suppliers appears warranted in complex industries and for expensive parts (such as jet engine parts).[216] In general, while increasing the indirect costs associated with conducting supplier development, supplier development efforts should decrease part cost and improve quality.[217]

More supplier development will...

1. Increase the cost of working with each supplier.

   - The cost of executing supplier development is captured in two ways. There is the ongoing cost of continually working with the current supply

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214 Phillips, Cheryl L. M. and V. R. Rao Tummala, "Maximizing Purchasing Synergies," *Practix*, Volume 5 Issue 3, March 2002, pp. 18-21.

215 There was much discussion between the Oklahoma City ALC personnel regarding the Air Force's ability to apply this improved leverage to decrease prices. While some felt the Air Force was already getting the best possible price though the use of certified cost and pricing data, others felt leverage could result in further cost savings. One individual who participated in writing a recent corporate (consolidated) contract felt the consolidation of requirements made the supplier more responsive but that the Air Force, rather than seeking price reductions, used this leverage to improve performance through decreased delivery times and quality improvements.

216 For a more detailed discussion of when supplier development efforts are most warranted see: Bensaou, M. and Erin Anderson, "Buyer-Supplier Relations in Industrial Markets: When Do Buyers Risk Making Idiosyncratic Investments?" *Organization Science*, Volume 10, Issue 4, Jul-Aug 1999, pp.460-481.

217 Patterson, James L. and J. Dougal Nelson, "OEM Cycle Time Reduction Through Supplier Development," *PRACTIX Best Practices in Purchasing and Supply Chain Management*, Vol. 2 Issue 3, March 1999, pp. 1-5.

base as well as an additional one time cost at the beginning of each contract to establish the relationship.

- As the cost of supplier development is a function of both the degree of integration as well as the number of suppliers, it will increase linearly with increases in the number of suppliers.

2. More supplier development will reduce the average purchase cost of items.[218]

   - By design, improving the practices of the suppliers will reduce the cost of producing parts, which in turn should reduce the total cost of parts.[219] This reduction comes in two parts, some of what is learned will only affect the prices paid in the current contract and will not survive the contract period, while a portion of what is learned during supplier development efforts can be passed on to future suppliers and will reduce the costs of parts sourced from all suppliers.[220]

   - As the most beneficial cost reduction projects will be undertaken initially and further development efforts will yield smaller levels of improvement, supplier development is assumed to reduce purchase price at a decreasing rate, modeled with the change in price as a function of the square root of the level of suppliers development.

3. Decrease the time required to monitor each supplier.[221]

   - With more integrated procedures, supplier performance will improve and reduce the amount of time spent "firefighting" unanticipated problems. This will increase the number of suppliers each employee can monitor.

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[218] Trent, Robert J., "Applying TQM to SCM," *Supply Chain Management Review*, May/June 2001, pp. 70-78.

[219] An example of how supplier development can reduce costs and improve quality can be found in: Berlow, Marc, "Medal of Excellence: For superb supplier development-Honda Wins!" *Purchasing*, September 21, 1995, pp. 32-40.

[220] The model assumes that in some but not all cases, the same supplier will be used in the future to source the items that benefited from the supplier development efforts. In the cases where the same supplier is used, the supplier development efforts should yield long-term improvements. In the case where new suppliers are used, the improvements from this supplier development effort will end with the expiration of the current contract.

[221] Steele, Paul T. and Brian H. Court, "*Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness Through the Skills of Purchasing*," London: McGraw-Hill Book Company, 1996, p. 26.

- Increased levels of supplier development are assumed to be inversely related to supplier monitoring costs, with a 20% reduction in supplier monitoring costs possible when supplier development efforts are three times the level present in the base case.

4. Increase the amount of effort required to award each individual contract (number of employee hours).

   - The use of supplier development will add additional clauses to the contract increasing the time required to award these contracts. In this model it is assumed that this increased time will be sourced from additional personnel and not extend the overall time required to award a contract.

   - The amount of effort required to monitor each contact is assumed to decrease at an exponentially decreasing rate, with increases in the level of supplier development with a 10% reduction in monitoring costs associated with doubling the amount of supplier development effort.

5. Increase the percentage of certified vendors.

   - With improved business practices, more suppliers will become certified either by the Air Force or an outside certification authority (i.e. ISO 9000).

   - Increases in supplier development will increase the percentage of certified vendors at a decreasing rate, modeled with the change in percentage of certified vendors as a function of the square root of the level of suppliers development. The model assumes that doubling the level of supplier development increases the number of certified vendors by 40% of the number certified in the base case.

6. Decrease the percentage of defective parts.[222,223]

   - With improved procedures, the number of defective parts received by the Air Force will be reduced.

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[222] An example of how supplier development can reduce costs and improve quality can be found in: Berlow, Marc, "Medal of Excellence: For superb supplier development- Honda Wins!" *Purchasing*, September 21, 1995, pp. 32-40.

[223] Sometimes quality improvements cannot just be required in contract terms, but require buyer's intervention into the supplier's processes to improve performance. For an example from the automotive industry see: Liker, Jeffrey K. and Yen-Chun Wu, "Japanese Automakers, U.S. Suppliers and Supply-Chain Superiority," *Sloan Management Review*, Fall 2000, p. 81-93.

- Increases in supplier development will decrease the percentage of certified vendors at an exponentially decreasing rate with doubling the level of supplier development decreasing the percentage of defects by 30% of the number present in the base case.

7. Decrease Production Lead Time.

   - Improving a supplier's processes and practices will (in general) reduce the amount of time suppliers need to produce their parts.[224] This decrease will affect the overall PLT of parts in general as some of the things learned during supplier development activities can be exported to other contracts and suppliers. In some cases, there will be additional contract specific reductions that only affect the current contract (i.e. some changes may be contingent on temporary arrangements such as the use of government furnished equipment that may nor may not be present in future contracts). Contract specific reductions affect each commodity group differently and require some time to materialize (In this model, contract specific improvements begin after a contract has been in place for one year and stop increasing after the second year).

   - Increases in the level of supplier development are inversely related to the production lead time, with a 25% reduction in PLT possible when supplier development efforts are 300% larger than in the base case.

8. Decrease Administrative Lead Time.

   - As the Air Force learns how to form relationships with suppliers that are more efficient, the time required to place an order will decrease. This could be through the use of a more efficient ordering process (i.e. standardizing part numbers between the Air Force and suppliers), or the increased use of electronic ordering mechanisms such as online ordering or electronic data interfaces between Air Force and supplier systems. Part of this reduction works for all contracts as the Air Force learns to become more efficient in placing orders. However, some of the reduction to ALT works within a given contract and this portion of the ALT reduction is lost when the contract expires.[225]

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[224] This is particularly true with small businesses, which may lack the resources or ability to improve their own processes. Patterson, James L. and J. Dougal Nelson, "OEM Cycle Time Reduction Through Supplier Development," *PRACTIX Best Practices in Purchasing and Supply Chain Management*, Vol. 2 Issue 3, March 1999, pp. 1-5.

[225] For example, if the Air Force establishes an electronic data interface with a given supplier, this will greatly reduce the ALT for this supplier but have little effect on other suppliers. When the contract with this supplier expires, unless it is renewed, the improvements from investing in this

- Administrative lead times are reduced at a decreasing rate with increases in supplier development, modeled using a square root functional form. This reduction reaches a maximum of 20% when supplier development efforts are tripled and a part has been on contract for longer than 36 months.

Inventory Levels

The inventory levels are set to provide enough parts to meet the average demand rate for a given period of time (usually (ALT+PLT+Delivery Time) multiplied by Failure Rate) plus some additional safety level. Increasing the quantity of inventory on hand decreases the probably of having shortages but also ties up and consumes resources.

Higher inventory levels will...

1. Increase holding costs.

   - More items to store requires additional storage space and personnel to mange this stored inventory. This includes the opportunity cost of capital used to purchase the inventory.

   - In the model, monthly inventory holding costs are modeled as a fixed rate of $1 per part and 0.05% of the parts value.

2. Increase the percentage of defective parts.

   - With more parts in the inventory, parts will spend more time on the shelf. This increased time delay increases the likelihood that the part will be damaged during its storage period. This could be from physical damage due to moving the part, while certain items (like electronics or rubber parts) have increased failure rates with age with or without use or physical handling. Thus, the propensity for damage during storage is different for each commodity group.

   - The percentage of defects while held in inventory varies categorically by the type of part as well as linearly with the number of parts in inventory. It is assumed that if inventory levels are doubled, the percentage of defective parts will increase at most 10%, with lower defect rates possible

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exchange will be lost. However, other initiatives, such as improving the efficiency in which the Air Force prepares and distributes orders to all suppliers (either through a direct connection such as the Internet or better data sharing in general), will result in long term improvements that outlast a particular contract.

using different adjustment factors for each type of part held in inventory. For example, as modeled hardware items have a defect rate that is one-tenth this base rate, while electrical components are assumed to break at a half this base rate.

Length of Contract

While the Air Force receives its funding on an annual basis, it retains the ability to award multiple year contracts. By adding additional "option" years to a basic contract, both parties in the relationship can be assured that future requirements will be sourced using this contract. While the length of an individual contract will be determined by examining a variety of factors such as the stability of the market place, the certainty of the requirement, etc., in general the Air Force can stress the use of shorter or longer contract lengths. This parameter represents the targeted average contract length.

Longer Contracts will…

1. Increase contract award time.

   – Longer contracts have more option years to negotiate, adding additional complexity to the award process. These contracts also have a higher total dollar value, leading to increased scrutiny and levels of management review.

   – Contract length works in tandem with the number of contracts/supplier. Increasing length while reducing the number of contracts per supplier compounds the complexity of the effort and further increases award time.

   – Contract award time is modeled to increase at a decreasing rate with contract award time increasing at a rate that is a function of the square root of the contract length. For example, doubling the contract length would increase the average award time by 7%.

2. Increase individual contract award cost.

- As with award time, contracts that have more option years are more complex and cost more to award.[226] However, as contracts are re-bid less often the total cost of awarding contracts over time is reduced.

- Similar to award times, contract award costs are modeled to increase with the square root of the average contract length.

3. Increase the amount of effort to monitor the contract.

   - In general, longer contracts will be older contracts and to remain current may require more extensive modification than shorter duration contracts. This will decrease the number of contracts managed by each employee.

   - Contract monitoring costs increase at a logarithmically decreasing rate with longer contract lengths. These additional years add complexity to the contracts but also become more familiar with contracting managers who are responsible for their oversight. For example, in the base case, increasing the average contract length from 1 to 2 years increases contract monitoring costs by 9%.

4. Increase the number of suppliers each employee can monitor.[227]

   - While longer contracts are more difficult to administer from a contracting perspective, from a supplier management perspective longer contracts will result in fewer changes in suppliers and fewer contract changes with each supplier. Thus, supplier management will become easier and the number of suppliers/employee will increase.

   - With little empirical data, supplier monitoring efforts are considered to decrease linearly with changes to the average contract length. In the model, the number of suppliers each employee can manage is decreased by 0.1% for each month the average contract length is extended.

5. Will improve Administrative Lead Time.

   - With a longer contract period, the Air Force can work together with the same supplier over time to improve the interaction of the two

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[226] This does not imply that the net effect of lengthening contracts is to increase total indirect costs. With fewer contracts to award, the effect on the total cost of awarding contracts is indeterminate.

[227] For an example of where longer contracts reduced personnel costs see: Dyer, Jeffrey H., "How Chrysler Created an American Keiretsu," *Harvard Business Review*, July 1, 1996.

enterprises.[228] While having a single source for a part mitigates some of this improvement, without a contractual guarantee the government may elect to repair these parts in the future rather than purchasing them from suppliers. Thus, except for sole source parts, longer contracts reduce uncertainty regarding the future of the relationship between the Air Force and the supplier, incentivizing them to make additional investments in new policies or procedures to reduce the friction between the two enterprises.

- For sole source parts, ALT is unchanged. For all other parts, ALT is inversely related to the contract length with a doubling of contract length reducing ALT by 12.5%.

6. Will decrease the percentage of parts that are defective.[229,230]

   - With the same supplier working from the same contract for a longer period of time, any misspecifications of part requirements can be corrected and part quality should improve.[231] The presence of supplier development will accelerate this learning curve and increase the rate of improvement over time.

   - Model currently assumes an inverse relationship with a maximum improvement of 10% with a 5-year contract length target. This improvement is multiplied by the amount of supplier development effort present.

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[228] Oklahoma City ALC personnel have found this to be one of the most significant benefits of extending the length and breadth of the contract. Points of contact for both the Air Force and suppliers have stabilized reducing the friction encountered when communicating between the two enterprises.

[229] One of the benefits of contract lengths over 1 year is the increased presence of efficiency programs and the ability of suppliers to progress down a learning curve, improving part quality. Steele, Paul T. and Brian H. Court, "*Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness Through the Skills of Purchasing*," London: McGraw-Hill Book Company, 1996, p. 47.

[230] Longer-term agreements provide evidence of buyer commitment and promote continuous improvement improving part quality. Additionally this longer-term commitment encourages suppliers to invest in quality-improving capital equipment. Trent, Robert J., "Applying TQM to SCM," *Supply Chain Management Review*, May/June 2001, p. 76.

[231] In a survey of 162 companies, it was found that long-term partnerships improve the quality of items and decrease costs. Graham, T. Scott, Patricia J. Daugherty, and William N. Dudley, "The Long-Term Strategic Impact of Purchasing Partnerships," *International Journal of Purchasing and Materials Management*, Fall 1994, pp. 13-18.

Joint Forecasting

In traditional sourcing efforts, the Air Force determines the requirement internally and passes this information to contracting personnel for sourcing. These requirements are stated in definitive terms and presented to the suppliers as a given. However, an alternative process can be used where the Air Force works with the suppliers to jointly estimate the size of future requirements. The extent of this cooperation can vary from sharing source data and allowing each party to make their own forecast, to meeting and jointly determining a common vision of what the future requirements will be. This parameter reflects the degree of mutual participation that is present in forecasting future requirements. The model assumes that joint forecasts will be more accurate[232] but will not affect the actual requirement for parts into the future and on average; the projected demand represents an unbiased estimate of the actual demand.

More will…

1. Increase the total cost of purchasing items (placing orders).

   - Buyer and supplier personnel must now participate in the forecasting efforts and this participation comes at a price. While this cost may or may not be an explicit line item in the contract, it is actually a change in the transaction cost of ordering parts and should not be part of the purchase price of the item.

   - The presence of supplier development reduces the cost of conducting joint forecasting, as one aspect of supplier development is to better integrate the procedures of the two enterprises. Thus, any joint activity will be more efficient with increased levels of supplier development.

   - This effect is assumed to be small, with the cost of placing orders linearly increasing 3% with a 100% increase in the amount of joint forecasting present. This increase is reduced in proportion to the level of supplier development present (e.g. doubling supplier development halves the rate of increase to 1.5%.)

2. Decrease Production Lead Time.[233,234]

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[232] For commercial examples of how joint forecasting can improve the accuracy of the forecasts an average of 12% see: Buxbaum, Peter A., "Psyched Up," *Operations & Fulfillment*, March 1, 2003.

[233] One of the primary benefits of joint forecasting is the reduction in inventory possible when administrative and production lead times are reduced. Coyle, John J., Edward J. Bardi, and C. John Langley, Jr., *The Management of Business Logistics: A Supply Chain Perspective, 7th Edition*, Mason, Ohio:South-Western, 2003, p. 579-581.

- With forecasts developed jointly, suppliers will be more aware of future requirements and can be better prepared to react to them.
- This reduction in PLT will be even greater with the presence of supplier development efforts to better integrate the two enterprises.
- The use of performance measures enhances this reduction in PLT; as vendors are more inclined to make changes to their processes to meet changes in future requirements if they can benefit from this performance improvement.
- Increases in the level of joint forecasting are inversely related to the production lead time. As joint forecasting not only improves the accuracy of the forecast it makes suppliers more aware of future requirements allowing them to prepare ahead for future orders. The effect of joint forecasting is assumed to be significant, with a 50% reduction in PLT possible when joint forecasting efforts are 300% larger than in the base case.

3. Increase the time required to work with/monitor each supplier.
   - The relationship with each supplier now includes the participation in joint forecasting efforts, increasing the buyer's effort as well as the suppliers. Thus, additional Air Force personnel will be needed to coordinate the joint development of a joint forecast of future requirements.
   - This increase will be even greater with the use of IPTs, as the number of personnel involved in the process will be greater.
   - Supplier development partially mitigates the time increase, as with more significant supplier development activities the two enterprises will have a more efficient method of interaction.
   - As initial increases in joint forecasting require the establishment of procedures and links to conduct the joint forecast, while more extensive use comes at a reduced cost by taking advantage of already established procedures, joint forecasting is assumed to be inversely related to supplier monitoring costs. For example, doubling the level of joint forecasting results in an 11% increase in supplier monitoring costs.

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[234] Multiple personnel at Oklahoma City ALC felt this was the most significant effect of joint forecasting activities. Better information on future demands ensures suppliers are prepared for future Air Force demands allowing them to better plan for and meet these requirements.

4. Decrease the effort required to place an order.

   – With the suppliers more aware of future requirements, they will be better prepared to accept these orders decreasing the effort required to place the order.

   – This effect is assumed to be minor, as no changes in the actual ordering process are made. The effort associated with placing an order is decreased at a linear rate of 1% with every 100% increase in joint forecasting.

Performance Measures

Regardless of the basic contract type, adding the right incentive clauses induce the supplier to perform above and beyond the basic minimum contractual requirements or to explicitly describe the penalties for non-compliance.[235] The presence of these performance incentives will increase the complexity of the contractual arrangement but, if used properly, should improve overall performance by the supplier.[236]

Their increased use will...

1. Increase contract award time.

   – Contracts with additional clauses take longer to negotiate and award.

   – It is assumed that adding additional clauses for performance measures to a contract increases contract award times at a linear rate, with each doubling in the use of performance measures resulting in a 5% increase in contract award time.

2. Increase contract award cost.

   – This increased effort will also increase the cost of awarding a contract.

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[235] For a description of different contract arrangements and their use to include incentive contracts which utilize performance measures see: Dobler, Donald W. and David N. Burt, *Purchasing and Supply Management: Text and Cases, Sixth Edition*, New York: McGraw-Hill Companies, 1996, pp. 340-355.

[236] Use of performance measures requires clear communication regarding the desired outcomes and feedback regarding supplier performance, but can result in improved performance and quality. Fawcett, Stanley E., *The Supply Management Environment, Volume 2*, Tempe, AZ: National Association of Purchasing Management, Inc., 2000, p. 121.

- Similar to contract award times, it is assumed that adding additional clauses for performance measures to a contract increases contract award costs at a linear rate, with each doubling in the use of performance measures resulting in a 5% increase in contract award cost.

3. Increase the effort required to process each order.

   - Similarly, more complex contractual terms will require additional monitoring to ensure each individual order is executed properly. This will decrease the number of orders/employee, as orders are harder to write and monitor.

   - The effort required to place orders using these performance clauses is also modeled using the same linear relationship as contract award effort, with each doubling of performance measures increasing the effort to award a delivery order by 5%.

4. Affect the price paid for all items.

   - Initially suppliers will require compensation for the increased uncertainty surrounding the contract; increasing the price of all items.[237]

   - In the longer term (for each contract), this increase is largely eliminated as suppliers adjust their processes and procedures to meet or exceed performance measures while reducing the amount of effort (cost) associated with non-value added activities.

   - As additional performance measures are used, it is assumed that suppliers will become less sensitive to their presence with potential price changes increasing at a decreasing rate. Reductions in price are modeled as a function of the square root of the level of performance measures used, with a doubling of performance measures decreasing the price of each part by a maximum of 11%. This percentage change varies by the type of part through the use of a multiplicative adjustment factor (i.e. for hardware this price decrease is reduced by 80%). However, this price adjustment is affected by the time a part is on contract. For contract periods less than 24 months, prices initially start <u>higher</u> than the base price by the adjustment factor, and as the contract matures the price of the part decreases at a decreasing rate until the maximum rate reduction

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[237] Multiple personnel from the Oklahoma City ALC stressed the point that any increased assumption of risk by the suppliers would result in higher prices to offset this risk. In economic terms, this implies that the suppliers are risk adverse a condition common to most firms (and individuals).

is reached at 24 months (prices are assumed to be exactly the base value after one year on contract).

5. Decrease Production Lead Time.[238]

   – With incentives to improve responsiveness, suppliers will reduce the amount of time needed to produce their parts. This decrease will affect the overall PLT of the part in general as some of the things learned by suppliers can be exported to other contracts, while other reductions will be contract specific and only affect the current contract.

   – Reductions in PLT are assumed to be linearly related to increases in the use of performance measures, with each doubling of performance measures decreasing PLT by 5%.

6. Improve part quality (reduce percentage of defective parts).[239]

   – Performance measures motivate suppliers to exceed basic contract specifications and the average quality of the parts should increase.

   – Reductions in the percentage of defects are assumed to be linearly related to increases in the use of performance measures, with each doubling of performance measures decreasing the percentage of defects by 10%.

Integrated Product Teams (IPTs)

The use of multi-disciplinary teams (Integrated Product Teams) to coordinate and execute the sourcing process ensures that all parties are working together to meet the actual requirement. The use of teams, while increasing the cost of sourcing effort ensures coordination of the efforts of all key participants at each phase of the sourcing process once a contract has expired.[240] As a means of

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[238] This assumes that production lead time is one of the performance measures with incentives. During discussions with OC-ALC personnel, they indicated that this was often an area that was motivated to reduce the average backorder delay resulting from waiting for parts to be produced when demands exceeded existing inventory levels.

[239] Personnel from Oklahoma City ALC saw this as the primary use of performance incentives; to improve the quality of the parts being received by the Air Force.

[240] When reviewing the use of IPTs in the DoD for the acquisition of new systems, the GAO found that while teams in general worked to improve the performance of the process, the structure of the DoD's environment was not conducive to effective teaming and could be altered to improve performance. This model assumes these structural changes are not made, and IPTs will continue to operate in the current organizational structure. U.S. General Accounting Office (GAO), *DoD Teaming Practices Not Achieving Potential Results*, Report to the Chairman and Ranking Member, Subcommittee

ensuring that contract terms are correctly written, this parameter captures the prevalence of IPTs vice relying strictly on individual functional experts to complete the individual steps in the sourcing process.

While the formation of more proactive, highly organized, and effective teams that develop supplier relationships before a contract expires could greatly improve performance and reduce total costs, the results of many teaming efforts is less than anticipated.[241]

In the current version of the PSM model, teams are reactive and assumed to be composed of functional representatives who participate in one or more commodity or sourcing teams.[242] In this configuration, coordination and synergy is limited by the lack of full time commitment and focus. In the current Air Force structure, where personnel are functionally assigned, promoted, and managed this team structure is most likely to be utilized. Used in this manner, IPTs improve performance but at a cost of additional coordination, effort and delay in awarding contracts and delivery orders. Should more proactive teams be employed, the effects of IPTs may require revision.

More extensive use of teams will...

1. Increase the cost of awarding a contract.

   - Awarding a contract with an IPT requires the coordination of the entire IPT. This increases the complexity of the award process. Additionally, suppliers may have more than one point of contact during the award process further complicating contacts between the Air Force and potential suppliers. Assuming this additional coordination involves coordinating with additional personnel not contacted before the increased use of IPTs, it will increase the cost of awarding a contract.

   - With the number of interactions between interested parties increasing exponentially with increases in the number of parties, increases in the use of IPTs are modeled as increasing the cost of awarding a contract at an increasing rate using a quadratic functional form. However, as most of the contract award costs are associated with each functional

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on Readiness and Management Support, Committee on Armed Services, U.S. Senate, GAO-01-510, April 2001.

[241] Trent, Robert J., "Individual and Collective Team Effort: A Vital Part of Sourcing Team Success," *International Journal of Purchasing and Materials Management*, Fall 1998, pp. 46-54.

[242] For a discussion on the different types of teaming arrangements and the benefits of each see: Clark, Kim B. and Steven C. Wheelwright, " Organizing and Leading "Heavyweight" Development Teams," *California Management Review*, Spring 1992, pp. 9-28.

representative working on their portion of the process this increase is not extensive. Doubling the use of IPTs is assumed to increase contract award costs by 10%.

2. Increase the contract award time.

   - In general, the increased coordination between all team members will also increase the amount of time required to award a contract. This assumes that the team is not proactive and starts the award process prior to the lapse of the old contract but allow some contracts to lapse and some parts to remain without contracts as is the current practice in the Air Force.

   - Similar to the effect of IPT use on contract award costs, contract award times are assumed to increase at the same increasing rate and quadratic functional form.

3. Increase the effort required to process each order.[243]

   - Similarly, a larger team involved in the order process will increase the number of hours required to award each order. This will decrease the number of orders/employee. This assumes that the method of awarding orders is not automated or streamlined. The amount of calendar time to award an order is not changed but with more individuals working in parallel, a larger number of employee hours is used to process each order.

   - Changes in the amount of effort required to place an order is assumed to be proportional to the change in effort required to award the contract. Thus, increases in the use of IPTs are modeled as increasing the cost of awarding a delivery order at an increasing rate using a quadratic functional form. Doubling the use of IPTs is assumed to increase delivery order award costs by 10%.

4. Increase the time required to monitor a contract.

   - As changes to the contract now require the coordination of the entire team, the number of contracts/employee will decrease with the use of

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[243] This effect assumes that IPTs are used for all aspects of the PSM process, and are not disbanded after contract award. For and IPT to be fully effective, members must be familiar with the day to day operation of sourcing a particular part (or set of parts) implying the continued use of IPTs after contract award in some form. This increased coordination during contract execution is the driver of increased hours to order parts and monitor contracts.

IPTs. As with order time, this assumes no change in the process or calendar time required, simply an increase in the total number of employee hours involved in contract oversight.

- Unlike the award of a contract, most of the contract monitoring effort is conducted by contracting and audit personnel. Thus, while IPT use will increase the number of people the contract monitors must be in contact with it does not exponentially increase the level of effort. It is assumed that increases in contract monitoring time are linearly proportional to increases in IPTS use, with doubling the level of IPT use modeled as increasing contract monitoring time by 5%.

5. Decrease the percentage of defective parts.

   - With the participation of all interested parties throughout the award and execution of a contract, results in a well specified contract with fewer errors or omissions. This will improve the quality of parts delivered, by improving the supplier selection process and ensuring that better suppliers are selected and tasked to produce exactly what the Air Force requires.

   - The degree to which this quality improvement is realized will vary by the type of parts; with simple parts benefiting less than complex items requiring detailed contract terms and specifications.

   - The level of reduction in the percentage of defects is assumed to be linearly proportional to the level of IPT use, with in the base case the percentage of defects being reduced by 5% for each doubling in the level of IPT use. This base rate is adjusted for each type of part based on their sensitivity to mis-specification (e.g. electrical parts are 2.5 times more sensitive to mis-specification than hardware items).

D. Alternative Improvement Concepts

Within both the commercial and DoD environment, various purchasing, supply, and supply chain management strategies have been proposed to improve existing practices, each with its own unique approach. The DoD has selected commercial best practices from each of these strategies and adapted them to fit within the military's goals and objectives. Each strategy proposes a realignment of the roles and structure of an organization's PSM processes and practices, but vary in the degree that they recognize the shift from a functionally aligned mentality. For an improvement strategy to be fully effective, the roles of purchasing (buying a given part) and supply management (determining which parts to buy, when to buy, and where to stock) must transition from separate and distinct activities to a more integrated approach to the sourcing of goods and services.[244]

The adoption of the policies of PSM is the most recent Air Force improvement approach and is part of its overall Spares Campaign to improve the spares supply process (Item 8 in Table A).[245] However, PSM is not the only approach to reform proposed to address this concern. This approach like others which seek to improve the performance of the Air Force acquisition and logistics systems is only one of several that have been proposed over the past few years to address the difficultly the Air Force and many commercial enterprises have had sourcing and supporting customer requirements. Other Air Force and DoD initiatives include acquisition reform, multiple versions of strategic sourcing and supply chain management, in addition to PSM. Table P depicts the various approaches discussed in this appendix and their relationships to each other. As indicated, each alternative reform approach has a slightly different strategy on how to best improve the support provided to the warfighter. Without a common understanding of the different approaches and their tenets, a meaningful discussion of the pros and cons of a particular improvement concept such as PSM is incomplete.

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[244] Kraljic, Peter, "Purchasing Must Become Supply Management," *Harvard Business Review*, September 1983.

[245] The Air Force is adopting the concepts of PSM under the leadership of a Purchasing and Supply Chain Management IPT at HQ AFMC. For the status of this effort see: Tinka, Marie and Scott Correll, " Improving Warfighter Readiness Through Purchasing and Supply Chain Management (PSCM) Transformation," HQ AFMC, PSCM IPT briefing, June 2003.

Table P: Alternative Improvement Concepts

Initiative	Focus	Scope	Leadership
Acquisition Reform	AF Acquisition Process	Acquisition, Support, Base Operations	Acquisition Community
Strategic Sourcing	Contractual relationships with suppliers	Procurement Activities	Contracting
Supply Chain Management	Physical flow of material	Supply Chain	Logistics
PSM	PSM combines the concepts of Strategic Sourcing and SCM in an integrated strategy.		

Acquisition Reform

Acquisition Reform (renamed Acquisition Excellence in 2002) started in 1995 and is an ongoing effort by the acquisition community to facilitate the implementation of individual reform initiatives.[246] This strategy achieves efficiencies toward a "better, faster, and cheaper" acquisition system by taking installation, system, and sustainment improvements suggested by the work force and industry. The process blends ongoing reform activities across the entire acquisition, sustainment, and operational community. Acquisition Reform establishes ad hoc reinvention teams to study, develop, and test candidate initiatives before deploying them across the acquisition community. Acquisition Reform emphasizes continuous communication and feedback, education, and follow through on performance gains for all reform activities.

While the Air Force's Acquisition Reform effort covers all phases of the acquisition process from initial purchase through operation and support, it lacks an overall strategic plan to guide the long-term structure of the initiative. Ideas are solicited from the bottom-up with each team working independently, and de-conflicted at the headquarters' Air Force level with a leadership council. Those that are to be implemented Air Force wide are then distributed as "Lightening Bolts."

Acquisition Reform's primary limitation with respect to improving the logistical support of Air Force systems is the fact that it is organized and led by

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[246] U.S. Secretary of the Air Force, Acquisitions, Acquisitions Excellence homepage, November 12, 2002. Online at www.safaq.hq.af.mil/acq_ref (as of November 12, 2002).

the acquisition community (rather than being directly focused on support issues). It does not directly address the problems of the sustainment process, which includes the maintenance, repair, and overhaul of weapon systems as well as the logistics system to support that maintenance effort. Thus, as a strategy to improve the PSM process, the acquisition reform initiative promises only marginal improvement over the current practice. Addressing weapon system design problems will reduce costs by improving the reliability of individual components but large-scale savings on the cost of all parts is not likely. Without directly examining the logistics system and the PSM process, significant improvement has not materialized with regards to the efficiency or effectiveness of this process.

Strategic Sourcing

Strategic Sourcing represents an alternative improvement approach that is focused on the procurement process. The commercial literature describes Strategic Sourcing as an expansion of the procurement process to consider not only the source of supply for a particular item but also the best sources to meet all of the enterprise's supply needs for a particular commodity.[247] A commodity is a group of parts with similar physical characteristics, sources of supply and purchasing methods. For example, all jet engine bearings purchased by the Air Force can be considered one commodity as they come from similar manufacturers, have the same basic function, and are purchased from a limited number of bearing suppliers. Once the total requirements for the entire enterprise have been determined, as well as the core competencies required for a particular commodity group (the suppliers of that commodity), the particular sourcing strategy is developed.[248] Strategic Sourcing recognizes that the skills of purchasing professionals must extend beyond the purchasing task itself to include identifying the most appropriate methods of sourcing according to the importance of the item to the overall business objectives of the organization.

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247 Owens, Gregory, Olivier Vidal, Rick Toole, and Donovan Favre, "Strategic Sourcing: Aligning procurement needs with your business goals," in Gattorna, John, ed., *Strategic Supply Chain Alignment: Best Practice in Supply Chain Management*, Brookfield, VT.: Gower, 1998, p. 285.

248 Within the realm of strategic sourcing, a variety of criteria has been proposed to determine the best method of selecting the source for each commodity. These include the strategic importance of the commodity and the cost or financial impact on the profitability of the enterprise. Other models use different criteria, such as the ability of a source of supply to provide a competitive advantage (cost leadership, product differentiation, or focus) or the degree of demand flexibility needed from source of supply. For a more in-depth discussion on developing a strategic sourcing strategy see: Sislian, Eric and Ahmet Satir, "Strategic Sourcing: A framework and a Case Study," *The Journal of Supply Chain Management*, Summer 2000, pp. 4-11.

DoD Strategic Sourcing

Within the Department of Defense, strategic sourcing takes on a slightly different focus and is primarily concerned with determining if services currently performed in-house should be outsourced to other government or commercial agencies. For example, should security at a military installation be the responsibility of military police, a federal security agency, or contracted to a private security company.

Strategic Sourcing as envisioned by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics builds upon the A-76 competitive sourcing program to include re-engineering and other options for inherently governmental activities.[249] The A-76 competitive sourcing program focuses on the economic decision of who should perform a given task: should it continue to be performed by government personnel or contracted out to a private enterprise. While outsourcing is a major component of the DoD Strategic Sourcing initiative, it includes other alternatives. Strategic Sourcing encompasses all functions or activities that could be reengineered or consolidated regardless of whether they are inherently governmental, military essential or commercial activities.

As with Acquisition Reform, the scope of this initiative as implemented is limited, particularly when applied to the PSM process. The DoD version of strategic sourcing is not focused on achieving improvements in the effectiveness of the logistics system or the quality of the parts provided to the field. By focusing primarily on manpower areas only about one-third of the total Air Force expenditures are being reviewed, unlike efforts to manage the purchase of weapon systems, goods, and services which account for the majority of all Air Force expenditures for a given fiscal year.[250] While the Deputy Under Secretary of Defense (Installations) is charged with providing guidance and coordination to the individual component's initiatives, there is no central strategic planning body to coordinate efforts. Additionally this strategy lacks any efforts to manage

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[249] The A-76 program sets forth the procedures for determining whether activities identified as commercial should be performed under contract with commercial sources or in-house using Government facilities and personnel. While this program has been recently revised to make improve the strengthen the application of competition, incorporate additional FAR principles into the competition process, make government agencies accountable for results, and provide guidance for the development of inventories of all activities, the basic procedures have not changed. A summary of the new A-76 program changes can be found at: Office of Management and Budget, "Performance of Commercial Activities," Federal Register, Volume 68, Number 103, May 29, 2003. Online at: http://frwebgate6.access.gpo.gov. (as of July 22, 2003).

[250] Assistant Secretary of the Air Force (Financial Management and Comptroller), *United States Air Force Statistical Digest FY 2001*, Washington, D.C., 2002.

the supplier base or to leverage the purchasing of individual entities within the DoD. This limitation greatly restricts the amount of power the DoD can exert on suppliers to improve performance or reduce cost. However, as seen with past studies, significant cost savings are possible. The savings from 286 A-76 studies completed between 1995 and 2000 is estimated to be $290 million for fiscal year 1999 alone.[251] With cost and manpower reductions serving as the primary objective, and over 280,000 positions in the DoD being planned for review under the Strategic Sourcing and A-76 programs between FY 1997 and 2007, additional improvements in these areas is expected.[252]

AFMC/PK Strategic Sourcing

Unlike the DoD version of Strategic Sourcing, Strategic Sourcing as envisioned by Air Force Material Command Directorate of Contracting (AFMC/PK), is a commodity based process of developing business arrangements to support Supply Chain Management and the warfighter. Strategic Sourcing uses a disciplined, systematic process of effectively purchasing materials, products and services to make the supply chain more effective and efficient in support of the warfighter.[253] It focuses on leveraging AFMC's buying power, reducing cycle times, and improving supplier relationships.[254] These improvements are largely achieved with longer-term corporate contracts to form partnerships with suppliers and better align the incentives of the supplier with those of the Air Force.

In general, Strategic Sourcing represents an expansion of AFMC's procurement process from simply purchasing today's requirements to the development of channels of supply at the lowest total cost to the enterprise, not just the lowest purchase price. This approach has two primary limitations. First, by including only AFMC purchases in the analysis, and excluding items purchased by DLA and other military services, it lacks the scope needed to ensure that all items purchased from a particular supplier or needed to support a given weapon system are included. Secondly, it focuses primarily on the

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[251] U.S. General Accounting Office (GAO), *Results of A-76 Studies Over the Past 5 years*, Report to Congressional Committees, GAO-01-20, December 2000, p. 4.

[252] U.S. General Accounting Office (GAO), *A-76 Program Has Been Augmented by Broader Reinvention Options*, Testimony before the Subcommittee on Technology and Procurement Policy, Committee on Government Reform, House of Representatives, GAO-01-907T, June 2001, p. 6.

[253] Hazlett, Stuart, "AFMC Strategic Sourcing and Purchasing and Supply Management (PSM)," Briefing by HQ AFMC/PKL, July 19, 2001, p. 4.

[254] Seig, Stan, "AFMC Strategic Sourcing," Contracting Directorate Briefing to Air Force Material Command, August 24 ,2001, p. 37.

procurement aspect of the problem and lacks the larger scope and vision needed to truly transform the overall spares support process. For example, changes in the requirement determination process are generally not part of a Strategic Sourcing strategy but may greatly affect the ability to deliver required parts to the end customer. Like the commercial and DoD versions of Strategic Sourcing, this approach addresses the need for better purchasing practices but lacks the scope needed to transform the entire PSM process.

Supply Chain Management

As an alternative set of improvement approaches, Supply Chain Management (SCM) seeks to improve the management of the actual parts in the supply chain. SCM as defined in the commercial sector recognizes the need to expand the logistical process beyond the flow of actual goods to include the entire process of meeting customer needs.[255] SCM was initially defined as the integration of logistics and physical distribution functions with the goal of reducing delivery lead times.[256] This definition has been expanded to include forming partnerships and integrating key suppliers to reduce total supply chain costs and improve quality and delivery timing. SCM is now defined as, "a collaborative-based strategy to link inter-organizational business operations to achieve a shared market opportunity."[257] This is a broader concept that includes sourcing, manufacturing, and delivering required items.

SCM seeks to improve the efficiency of the end-to-end supply chain, beginning with developing long-term partnerships with key suppliers and then work to improve the interaction between the Air Force and these suppliers. The goals are primarily to improve quality, customer service, and delivery criteria rather than just achieving price reductions for a particular organization, which are achieved by integrating the key functions of the value chain such as purchasing, quality, materials management, and manufacturing or demand planning. Final customers are often not involved in the process.[258] Logistics communities primarily lead this change effort as the ones who understand the

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[255] Novack, Robert A., "Introduction to Supply Chain Management," in Cavinato, Joseph C. and Ralph G. Kauffman, eds., *The Purchasing Handbook: A Guide for the Purchasing and Supply Professional*, 6th Ed, New York: McGraw Hill, 2000.

[256] Wisner, Joel D. and Keah Choon Tan, "Supply Chain Management and its Impact on Purchasing," *The Journal of Supply Chain Management*, Fall 2000, p. 33.

[257] Bowersox, Donald J., David J. Closs, and Theodore P. Stank, *21st Century Logistics: Making Supply Chain Integration a Reality*, Oak Brook, IL: Council of Logistics Management, 1999, p. 6.

[258] Wisner, Joel D. and Keah Choon Tan, "Supply Chain Management and its Impact on Purchasing," *The Journal of Supply Chain Management*, Fall 2000, p. 36.

integration of all tasks required to deliver the final product. However, SCM recognizes that the purchasing function provides the crucial boundary-spanning link between sources of supply and the organization.[259]

Supply Chain Management's strength is its focus on the overall end-to-end process from suppliers to customers for providing goods and services to the final customer rather than individual stops in the process. This physical process based analysis is easy to grasp, measure, and seeks to improve the efficiency of the overall process. By reducing waste and redundancy and improving the effectiveness of the support provided to the end user. The greatest limitation of this strategy is its focus solely on the supply chain, rather than on the strategic goals and objectives of the organization. Taking the process as given and attempting to improve its efficiency and effectiveness may overlook the true desires of the end customer.[260] Additionally, with its use of long-term partnerships to improve supply chain performance, this strategy is not well suited to an organization that has a highly unstable supplier base. It sacrifices flexibility in switching between suppliers for efficiency, and fails to consider the need for revisions to current business practices and processes outside of improvements to the end-to-end supply chain (e.g., reduce the number of suppliers). Within the Air Force, this implies that changes are not needed in the current organizational structure, retaining the separation of acquisition, sustainment, and operational units.

DoD Supply Chain Management

Supply Chain Management as interpreted by the DoD (through support from the Logistics Management Institute) is a process designed to focus on the customer's requirements while working within the current DoD sustainment system.[261] The DoD defines SCM as an integrated process that begins with planning the acquisition of customer-driven requirements for material and services and ends with the delivery of material to the operational customer, including the material returns segment of the process and the flow of required

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[259] Ibid, p. 34.

[260] As noted by the OSD Director of Force Transformation, "... traditional practices in logistics and supply chain management work best with high levels of predictability and stability. They are simply not suited to the quickly evolving and adaptive behavior of future military forces." Cebrowski, Arthur K., Director of Force Transformation, Office of the Secretary of Defense, transcript of interview with *Information Technology Association of America*, August 1, 2002. Online at: http://www.oft.osd.mil/library/library_files/article_5_final_itaa_answer_1.doc (as of June 26, 2003).

[261] Logistics Management Institute, *DoD Supply Chain Management Implementation Guide*, McLean, VA: Logistics Management Institute, 2000.

information in both directions among suppliers, logistics managers, and customers.[262] As a basic change in approach from the current functional alignment, DoD SCM concentrates on the end-to-end process of ensuring that the operational requirements are satisfied at the point of need, but does not specifically address purchasing nor attempts to alter the number, quality, or stability of suppliers. To achieve this, customers are grouped by service needs and services are tailored to meet the needs of this segment.

AFMC/LG Supply Chain Management

The Air Force Material Command Directorate of Logistics' (AFMC/LG) version of Supply Chain Management is similar to that described in the business literature but takes a much narrower definition of the supply chain by analyzing the end-to-end supply chain for each individual commodity separately.[263] Unlike the literature's version, this approach seeks to work within the existing Air Force functional structure making it easier to implement but retains the integrated view of the entire supply chain to include suppliers and customers. AFMC/LG's version of SCM focuses at the commodity level within an individual supply chain (flight line, PDM/Overhaul, and Component repair). The overall organizational structure remains unchanged with improvements obtained by working within the existing organizational framework and processes to better integrate its participants.

All three Supply Chain Management strategies focus primarily on the physical supply process rather than the supplier relationships and the supply base for a particular commodity in question. Without the inclusion of the legal and structural aspects of the relationship (more of a purchasing focus), significant cost savings are unlikely and the incentives of the suppliers may not be aligned to meet Air Force objectives.

PSM

As noted earlier, the most comprehensive of the alternative improvement concepts, Purchasing and Supply Management (PSM) is a strategic, enterprise-wide, long-term, multi-functional, dynamic approach to

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[262] Ibid, p. 14.

[263] U.S. Air Force Material Command, "Guide to Supply Chain Management," HQ AFMC/LGI, September 1, 2002. Online at https://scm.wpafb.af.mil/master_plan/pamphlet.doc. (as of January 23, 2003).

selecting suppliers of goods and services and managing them. It includes the whole value network from raw materials to final customer use and disposal to continually reduce total ownership costs, manage risks, and improve performance (quality, responsiveness, reliability, and flexibility).[264] It focuses on developing long-term supplier relations with the best suppliers and integrating the supply chain to achieve mutual cost reduction, improved responsiveness, and quality improvement and is the broadest of all of the above strategies.

Using permanent, highly trained cross-functional teams focused on specific groups of strategic goods and services, supply relationships are formed and maintained to manage the supply base as well as individual suppliers. PSM stresses the need for all activities to remain clearly focused on the short- and long-term strategic goals of the organization. As reported in industry [265]there is a potential for significant improvement in the cost (reduced costs of more than 15% over time),[266,267] efficiency (delivery time improvements of 7-10%), and effectiveness (quality improvements of 10-13%) of the sustainment process.[268]

However, these great improvements come at a significant implementation "cost." PSM represents a dramatic shift in culture and structure from current Air Force contracting and supply practices and organizational structure. Fully implementing PSM requires an extensive reorganization. PSM combines roles of contracting, supply, and transportation creating a new entity. An organizational-wide perspective of optimizing the supply process replaces the traditional method of procuring individual items. Transformation to this new system requires the use of a fully robust change management process to include making a case for change, planning the change, implementation, and solidification of the new procedures. This complex undertaking requires a complete understanding of the current system and how changes will affect key

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264 Kraljic, Peter, "Purchasing Must Become Supply Management," *Harvard Business Review*, September-October 1983.

265 In an industry survey, it was found that "Disciplined companies frequently achieve a 10-15% benefit across all external purchases." Eversbusch, Andreas W., "Achieving Breakthrough Results Through Strategic Sourcing," Strategic Sourcing Management Conference, Institute for International Research, New Orleans, LA, February 9-11, 1998.

266 Owens, Gregory, Oliver Vidal, Rick Toole, and Donovan Favre, "Strategic Sourcing: Aligning Procurement Needs with Your Business Goals," in Gattorna, John, ed., *Strategic Supply Chain Alignment: Best Practice in Supply Chain Management*, Brookfield, VT: Gower, 1998, p. 286.

267 Chapman, Timothy L., Jack J. Dempsey, Glenn Ramsdell, and Michale R. Reopel, "Purchasing & Supply Management: No Time for 'Lone Rangers'," *Supply Chain Management Review.* Winter 1998, pp. 64-71.

268 Trent, Robert J. and Robert M. Monczka, "Purchasing and Supply Management Trends and Changes Throughout the 1990s," *International Journal of Purchasing and Materials Management*, Fall 1998, pp. 3-4.

stakeholders and the measures of interest. Without this understanding, creating and maintaining the focus needed to successfully complete this transformation is unlikely.[269]

Summary

It is clear that no single strategy has the ability to meet all of the Air Force's goals of improved performance and reduced cost for all types of goods and services. Each of these initiatives has their strengths and weaknesses, and selecting the "best" strategy requires a more detailed analysis of each portion of Air Force's PSM process.

Two observations are clear from this review of the various alternative improvement concepts. First, each strategy comes from a slightly different perspective. This variation in focus changes the scope of the problem, the choice of a solution methodology, the likely rewards, and the ease of implementation. Even for a particular approach, there exist differences in the attributes, strengths, and goals of a particular strategy both in the literature and even within the Department of Defense. Second, the optimal solution depends upon the characteristics of the process being analyzed and the perspective of the analyst. Strategies that may work well for procuring highly complex and expensive weapon systems such as Acquisition Reform may not be optimal to procure routine commodity items.

The proper approach to analyzing a particular improvement initiative is to look at the individual attributes or changes associated with the initiative, and tailor the optimal solution to the particular system or group of items for which support is needed. This analysis should include the explicit discussion regarding the scope of the initiative as well as the specific objectives used to evaluate alternatives.

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[269] Kotter, John P., "Leading Change: Why Transformation Efforts Fail," *Harvard Business Review*, March-April 1995, pp. 59-67.

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