Improving Complex Enterprises with System Models

by

Justin M. Hemann

B.S. Aeronautical and Astronautical Engineering
Purdue University, 1999

Submitted to the Engineering Systems Division in Partial
Fulfillment of the Requirements for the Degree of

Master of Science in Engineering Systems

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ABSTRACT

Air Force sustainment operations are the focus of an intensive internal effort to improve performance and reduce costs. Past improvement initiatives have often failed to produce the intended results, and have caused performance to decline in some cases. Exploratory research was conducted at an Air Logistics Center to study how improvements are executed.

Two conclusions are drawn from this research. The first is that changing sustainment operations is a problem of high dynamic and behavioral complexity. The second conclusion is that system models are well suited to coordinating change at the ALC because they provide insight into how a complicated system can be managed and improved. Three key findings support these conclusions. First, there is significant correlation between categories of unavailable F-16 aircraft such that reductions in one category are associated with increases in another. Second, an analysis of change efforts in two parts of the ALC shows that systemic influences, such as the inability to reinvest in improvements, are hindering change initiatives in one part of the ALC. The third finding is that a model of sustainment operations suggests that independent improvement initiatives are outperformed by coordinated efforts driven with an understanding of systemic interactions.

Leaders throughout the sustainment community have expressed their desire to understand how sustainment operations function as a system. A hybrid approach to change is offered as a method for understanding and improving sustainment operations. System models are used to quantify and model system interactions; then policies and recommendations are drawn from the models. Recommendations may include process-level improvements utilizing change methods already in use at the ALC

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Principal Research Associate

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Glossary and Acronyms:

AFMC	Air Force Materiel Command
ALC	Air Logistics Center
BRAC	Base Realignment and Closure
CBO	Congressional Budget Office
DLA	Defense Logistics Agency
DoD	Department of Defense
EVSMA	Enterprise Value Stream Mapping and Analysis
F-16	A multi-role fighter jet, also called the Fighting Falcon
Flow days	The number of days it takes an aircraft or component to complete a process.
GAO	Government Accountability Office or General Accounting Office
IM	Inventory Management
MC	Mission capability, a measure of how many aircraft are available for missions. This measure does not include aircraft that are undergoing depot maintenance, unlike system availability.
NMCB	Not Mission Capable for maintenance and supply, unscheduled or scheduled rate
NMCM	Not Mission Capable for Maintenance, unscheduled or scheduled
NMCS	Not Mission Capable for Supply
O&M	Operations and maintenance
OO-ALC	Ogden Air Logistics Center
R&M	Reliability and Maintainability
REMIS	Reliability and Maintainability Information System
System availability	A measure of how many aircraft are available for missions. This measure does include aircraft that are undergoing depot maintenance, unlike MC (mission capability).
TNMCS	Total Not Mission Capable for Supply, NMCS + NMCB
VSM	Value Stream Mapping
WCF	Working Capital Fund

1 Introduction

> Successful problem solving requires finding the right solution to the right problem. We fail more often because we solve the wrong problem than because we get the wrong solution to the right problem.
>
> Russel Ackoff (1974)

Ackoff's observation raises a question: how do we determine the right problem? The importance of this question cannot be overstated because the problem shapes the solution method. Consider the apocryphal story about the owner of a tall office building and the tenants who complained about long wait times for elevators. Engineers proposed to add elevators, an expensive solution to the problem. The owner decided instead to install floor to ceiling mirrors by the elevators on each floor. Complaints dropped immediately. Tenants who used to wait in frustration found themselves unhurriedly checking their hair, makeup, and neckties. Engineers had framed the problem as one of moving people between floors, while the owner focused on reducing the annoyance that caused complaints. Different problems resulted in different solutions.

Getting to the right problem can be especially challenging when faced with a set of interrelated or interdependent problems, or system of problems. "English does not contain a suitable word for 'system of problems.' Therefore, I have had to coin one. I choose to call such a system a *mess*" (Ackoff 1974, p21). This thesis endeavors to show that a particular set of problems is a *mess* that ought to be treated with systems methods.

1.1 Problem statement

The focus of this thesis is a change effort underway at a United States Air Force Air Logistics Center in Ogden, Utah. Leaders at the Center have set improvement goals shown in Figure 16, and they intend to meet those goals as efficaciously as possible. The overall problem is how to meet the improvement goals with the minimum amount of resources.

This thesis advances two contentions that were stated briefly in the introduction. First, that the change effort is system of problems with high dynamic and social complexity, and second, that managing change through systems methods is better than the methods in use. Support for the first contention will come from demonstrating the interdependent nature of the change effort. Enterprise change will be established at the upper-right quadrant of problems described in Figure 1. The second contention will be supported by addressing three questions. Namely, when compared with the improvement prioritization methods in use, does a systems approach...

1. ...lead to different conclusions?
2. Is it preferable?
3. How does the method influence the change process?

This thesis seeks to connect theory and practice. Every effort will be made to link abstract notions about systems methods to the concrete problems facing those who act in change efforts. Particular attention will be given to the scope of influence at the Air Logistics Center in Ogden, which hosted this research. However, this attention does not mean that the boundaries of the problem are drawn at the Center's fence. What it does mean is that certain results will be presented in a way that is useful to the Center leadership.

Leaders at the Air Logistics Center are one segment of the intended audience for this thesis. Another segment is those who seek to change organizations that fall under Ackoff's definition of a mess. This thesis may serve as a case study of applied systems methods for such an audience.

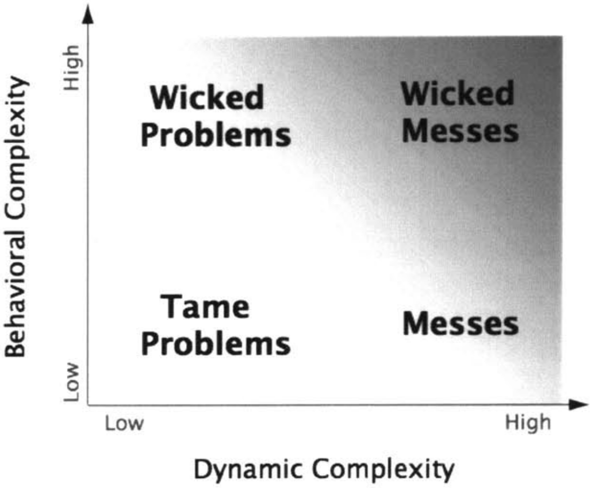


Figure 1: Problem domains. Mess is Ackoff's term (1974), while tame and wicked are Rittel's (1973).

1.2 Research methods

This thesis is based on data collected over the course of six visits to the Air Logistics Center in Ogden, Utah. The US Air Force invited members of the Lean Aerospace Initiative consortium to visit the center and participate in a change planning process. As a member of the consortium the author had access to a range of personnel at the base from the Vice Commander to technicians in maintenance shops.

Quantitative data came from a variety of sources within the Center, including the F-16 System Program Office, the Air Force database known as REMIS (Reliability and Maintainability Information System), and the depot Maintenance Wing. Qualitative data was gathered from interviews and observations made in meetings among Center personnel. Another valuable source of information was the significant body of work on Air Force sustainment produced by researchers and auditors. Air Force sustainment has been a recurring topic for RAND, the Government Accountability Office, and the Congressional Budget Office. MIT students and researchers have produced several Master's theses and papers on topics related to Air Force sustainment.

An exploratory approach was brought to the research. System dynamics and statistics were used to analyze data and produce insights, but the decision to apply these methods was made gradually over the research process, not at the outset. The overall objective was to use methods that were appropriate for the problem. Indeed, arriving at the problem statement was another exploratory process. Past attempts to change Air Force sustainment have often failed to produce the intended results, a finding that compelled the author to question why the attempts failed, and to not take the problem definition for granted.

2 Background

> When you are confronted by any complex social system, such as an urban center..., with things about it that you're dissatisfied with and anxious to fix, you cannot just step in and set about fixing with much hope of helping. This realization is one of the sore discouragements of our century... 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... Intervening is a way of causing trouble.
>
> Lewis Thomas (Thomas 1974)

Thomas describes what many call The Law of Unintended Consequences. While this law does not have scientific validation like, say, Newton's laws of motion, unintended consequences seem to be a feature of life just like apples falling from trees or planets circling the sun. To avoid "disastrous events" we must first understand what we are fixing.

This chapter provides context and support for the analysis to follow. It can be roughly divided into halves. In the first half the operation is described: Air Force sustainment, and, in particular, F-16 sustainment at the US Air Force Ogden Air Logistics Center in Utah. In the second half the focus turns to methods and techniques for understanding and changing sustainment operations.

2.1 Air Force sustainment overview

Air Force sustainment is one branch of the United States Department of Defense (DoD) sustainment organization. If DoD sustainment were a company it would be America's 8th largest with over $80 Billion in revenue in 1999. In 2000 sustainment accounted for 37% of the overall defense budget. The system has a truly global scope because it reaches wherever there are US troops. A network of more than 80,000 suppliers provides equipment and parts (DoD 2000).

Perhaps the best way to introduce Air Force sustainment operations is to step through a hypothetical case that follows an aircraft through the sustainment process. Figure 2 provides an overview that is described in a GAO report:

> The process used to repair failed repairable items begins when unit maintenance personnel at an Air Force base removes a failed item from the aircraft. At this point, base maintenance attempts to either repair the item or obtain a serviceable replacement from base supply. However, if base maintenance cannot repair the item and a suitable replacement item is not available, the base must (1) return the broken item to a maintenance depot for repair and (2) request a replacement from the appropriate inventory control point. The inventory control point, in turn, attempts to find a replacement in its existing wholesale inventory. If a replacement is not available, the inventory control point must either acquire a new one or repair a broken one. (GAO 1999b, p. 15).

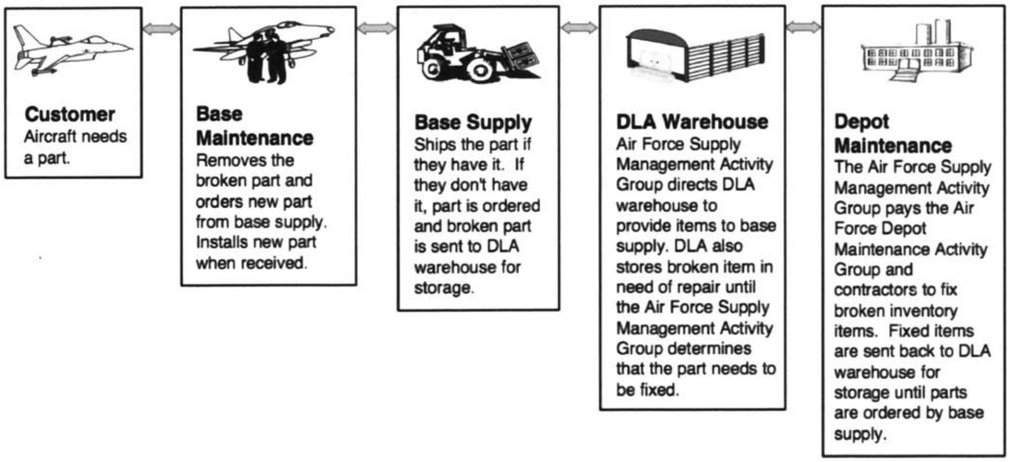


Figure 2: Sustainment operations overview (GAO 1999b, p. 16).

The operation outlined above handles a daunting array of parts and transactions. Approximately 172,850 types of parts (also called NSNs, National Stock Numbers) are managed, and there are over 600 million individual transactions per year. Performance data and management information is spread across 644 information systems. The overall response time is 29.8 days measured from the perspective of end-users at air bases, meaning that the wait for a requested part is approximate one month (USAF 1999).

2.1.1 Air logistics centers

Depot repair and supply management are the purview of three Air Logistics Centers (ALCs) in Utah, Oklahoma, and Georgia. There is both sharing and specialization in duties between the ALCs. For example, the Ogden, Utah ALC (called OO-ALC in Air Force parlance) hosts F-16 depot maintenance and logistics management, though some F-16 components, such as the engine, may be processed at another ALCs. Over 13,000 air force personnel, civil servants, and contractors work at the Ogden ALC with a majority - 70% - in the last two categories (CTPID 2004).

The ALCs were reorganized in late 2004 so that their structure would mirror operational wings - that is, units that fly jets. The reorganization was motivated by the desire to make sustainment operations more transparent to customers in operational wings. The previous organizational structure was unique and not recognizable to other branches of the Air Force. A new organization chart is shown in Figure 3. This thesis is primarily concerned with the activities of three wings in this chart: the Aircraft Sustainment Wing, the Combat Sustainment Wing, and the Maintenance Wing.

The Aircraft Sustainment Wing provides sustainment and acquisition expertise for the Air Force, other federal agencies, and foreign military sales, with a focus on components that are specific to a particular aircraft or platform. The Combat Sustainment Wing manages supply chain operations for commodities (e.g. nuts and bolts) and components such as landing gear and power systems. Combat Sustainment has a $1.5 billion annual budget and more than 850 staff members. Finally, the Maintenance Wing provides depot repair, modification, and maintenance for the F-16 Fighting Falcon, A-10 Thunderbolt and C-130 Hercules aircraft, and the Peacekeeper and Minuteman III intercontinental ballistic missiles.

The sustainment of F-16 aircraft is a topic of particular interest because this model composes such a large part of the US Air Force inventory. F-16 aircraft accounted for 56% of all US Air Force fighter / attack aircraft in 2000 (Bozdogan 2003). Therefore, the effectiveness of F-16 sustainment has a significant impact on the overall sustainment operations performance. An F-16 is shown in Figure 4.

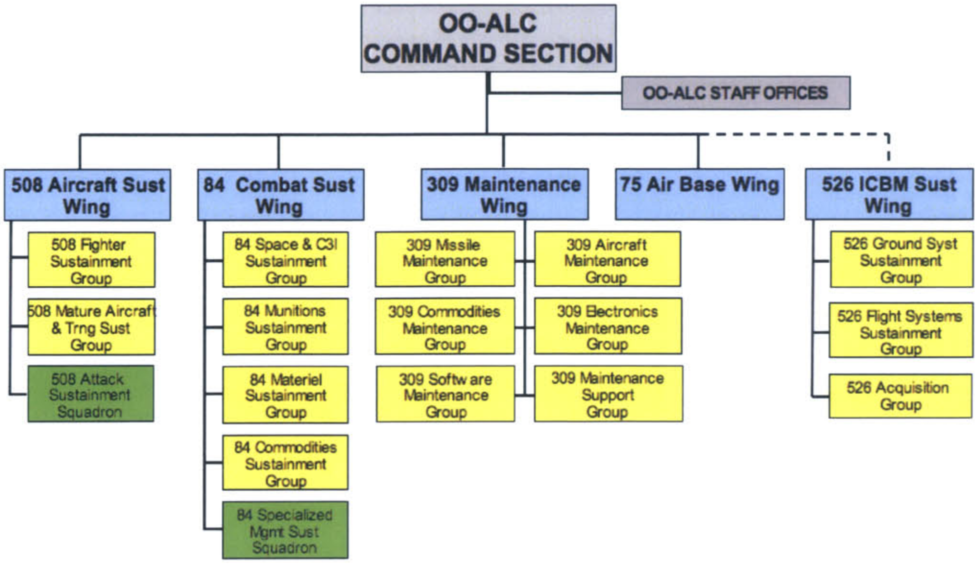


Figure 3: Organization chart for the Ogden Air Logistics Center (Wells 2004).

Figure 4: An F-16 at the Ogden Air Logistics Center.

2.1.2 Sustainment operations performance

Air Force sustainment performance is measured at a macro level by availability (how many aircraft are fit to perform a mission) and cost. The last two decades have seen a significant rise and fall in availability levels. Figure 5 shows that mission capability rates for fighter aircraft (including the F-16) peaked in 1991 at over 88% before dropping to approximately 75% over the next 10 years. More recent data from 2004 shows that F-16 mission capability levels are 78% (USAF 2005).

Another measure of sustainment performance is system availability, which is similar to mission capability, but not identical. Mission capable aircraft are counted from a pool that does not include aircraft undergoing depot maintenance. System availability does count aircraft in the depot. Therefore system availability rates will always be equal to or lower than mission capability rates. System availability may be a more meaningful measure of sustainment operations performance because it is based on the status of all aircraft.

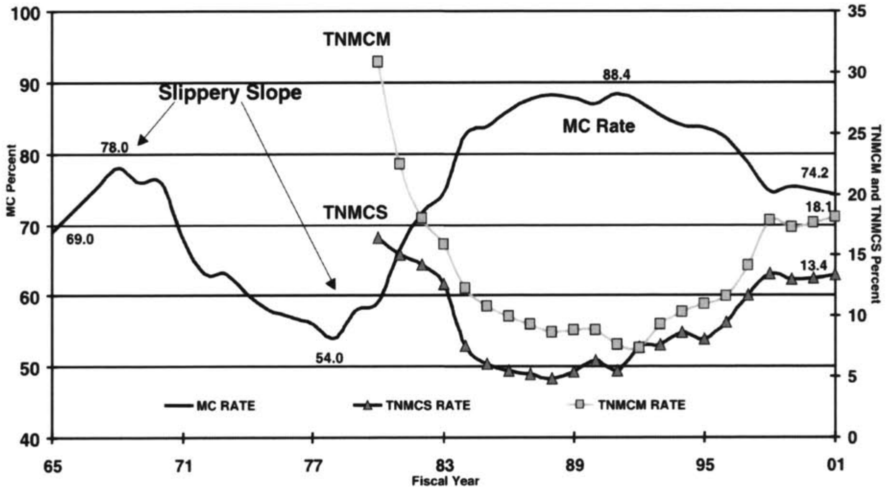


Figure 5: Mission capability rate for Air Force fighter aircraft (Oliver 2001).

While availability rates have dropped over the last 10 years, costs have not. Figure 6 shows that sustainment costs per flying hour have grown (measured in constant year 2000 dollars). Falling labor productivity is partially to blame; depot maintenance productivity fell 11.3% from 1992 to 1999 (GAO 2000). Rising sustainment costs are exacerbated by the fact that less aircraft are available for missions. There are approximately 1,350 F-16s in the US Air Force inventory, thus the drop in availability from 1991 to 2004 effectively reduces the number of available aircraft by 135. At 2005 prices of $35 million per plane, this represents $4.7 billion in value. In this calculation the F-16 availability rate was presumed to be the same as the overall fighter rate in 1991.

The decline in availability from 1991 to 2001 shown in Figure 5 can be linked with three major changes in the Air Force sustainment operations (GAO 2000). First, the number of personnel in the sustainment system has been reduced in response to declining force structures and increasing use of contractors - the Depot Maintenance Activity Group dropped from 31,000 in 1991 to 21,000 in 1999. Second, The Air Force made a major shift in maintenance processes from 1993 to 1997 by moving from a three level operation (organization, intermediate, and depot) to two levels (organization and depot). Third, the Air Force closed two of the five depots from 1995 to 2000 as a part of the Base Realignment and Closure process (BRAC). The closures caused significant disruptions to sustainment operations.

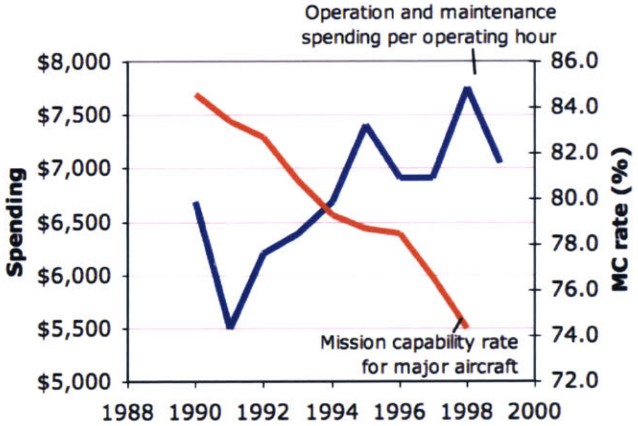


Figure 6: Air Force operating costs and availability (GAO 1999b) (CBO 2001).

What happens to aircraft when they are not available? Figure 7 shows how unavailable aircraft fall into one of four categories. The first is called NMCM (Not Mission Capable for Maintenance). When an aircraft malfunctions it is first placed in this category. Maintenance technicians at bases will diagnose the problem and replace parts if necessary. If the parts are not available then they will be ordered and the aircraft will change to NMCS (Not Mission Capable for Supply), or waiting for parts. The third and fourth categories pertain to depot maintenance. Aircraft are routinely taken out of service for planned inspection, upgrades, and repair, not unlike an oil change for a car. This is called scheduled depot maintenance. Unscheduled depot maintenance occurs when field maintenance personnel are unable to repair an aircraft. Depot facilities have greater repair capabilities than air bases. Some level of scheduled depot maintenance is unavoidable; especially since aircraft are regularly upgraded in the depot. Aircraft in the NMCS category can be reduced to zero in principle, but some aircraft will always fall in the NMCM category due to required inspections.

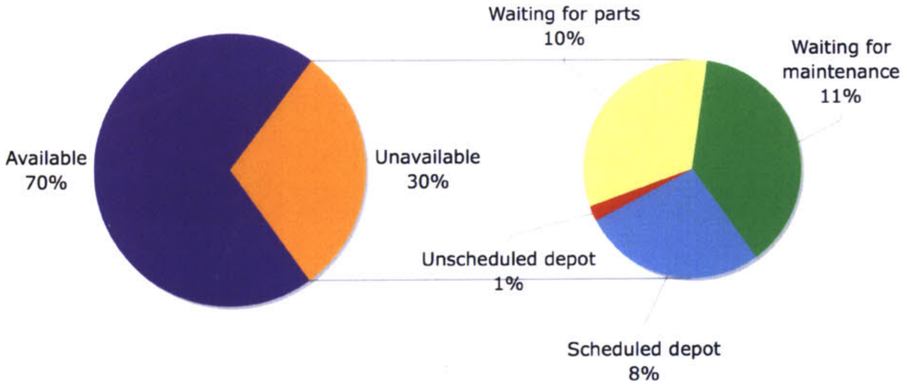


Figure 7: F-16 system availability, December 2003 - November 2004 (USAF 2005).

2.2 Related work in Air Force sustainment

US Air Force sustainment does not suffer from a lack of attention. Growing costs and declining availability performance have engendered scrutiny from a variety of sources within the Air Force, Department of Defense, Congress, think tanks, and academia. The following sections present a number of theses and reports that are relevant to this thesis. Special attention is given to findings that highlight the systemic nature of sustainment and the interrelationships between parts of sustainment operations. The work is divided between two sections; oversight reports and academic or analysis research. An overview of this work will provide a recent history of Air Force sustainment along with the trends and forces that have influenced the current conditions. These sections conclude with a synthesis of findings from the literature.

2.2.1 Oversight reports

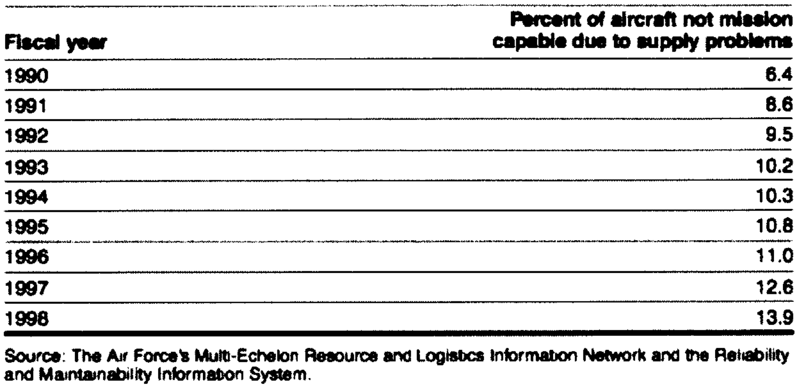
Oversight and analysis studies come from two sources: the General Accountability Office (GAO) and the Congressional Budget Office (CBO). As suggested by the office titles, these reports focus on waste, fraud, and abuse of government resources, and budgetary oversight. These reports are valuable in the context of this thesis because of their scope and access. GAO and CBO inspectors are free to reach across organizational boundaries and collect data from disparate sources. The reports are typically commissioned to investigate a specific phenomenon and develop recommendations for action.

Unintended consequences in Air Force sustainment

In the late 1990's the persistent parts problems within the US Air Force began to attract the attention of congress. The GAO issued a report focused on the effects of parts problems and the root causes (GAO 1999b). The report's title gives some indication of the findings: Management Actions Create Spare Parts Shortages and Operational Problems.

The "operational problems" mentioned in the title were widespread. Falling mission capability rates (see Figure 5) were just one symptom of parts shortages. Training goals were affected as well. Pilots for F-16 aircraft flew only 83% of their planned training hours in 1998, leaving some pilots without enough training to qualify as mission capable.

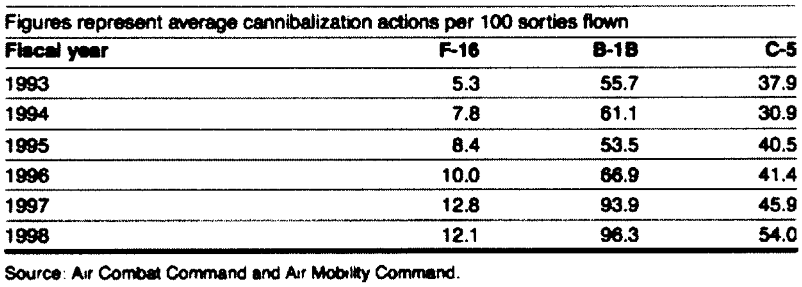
Supply problems were identified as the main cause of the shortfall. Indeed, the fraction of aircraft that is not available for missions due to supply problems more than doubled from 1990 to 1998 as shown in Figure 8. Maintainers dealt with parts shortages by increasing cannibalization rates – that is, the practice of repairing an aircraft by taking parts off of a non-mission capable aircraft. According to Figure 9 cannibalization rates more than doubled over five years. Cannibalization is generally undesirable because the practice doubles the workload for maintainers. They must remove a part from another aircraft instead of pulling a ready-to-use part from a shelf. Furthermore, the removal process may damage the part.



Fiscal year	Percent of aircraft not mission capable due to supply problems
1990	6.4
1991	8.6
1992	9.5
1993	10.2
1994	10.3
1995	10.8
1996	11.0
1997	12.6
1998	13.9

Source: The Air Force's Multi-Echelon Resource and Logistics Information Network and the Reliability and Maintainability Information System.

Figure 8: Total Not Mission Capable for Supply (NMCS) rates for major Air Force aircraft (GAO 1999b).



Figures represent average cannibalization actions per 100 sorties flown

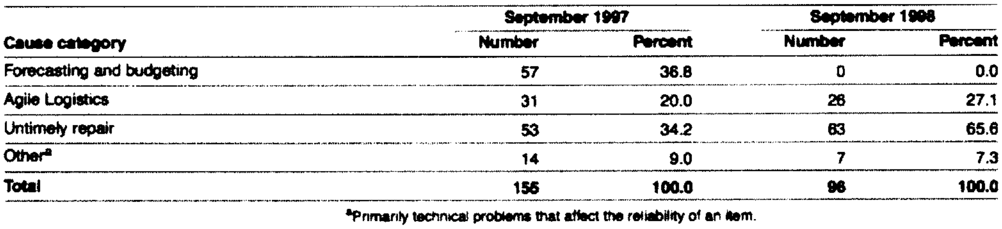
Fiscal year	F-16	B-1B	C-5
1993	5.3	55.7	37.9
1994	7.8	61.1	30.9
1995	8.4	53.5	40.5
1996	10.0	66.9	41.4
1997	12.8	93.9	45.9
1998	12.1	96.3	54.0

Source: Air Combat Command and Air Mobility Command.

Figure 9: Cannibalization rates for F-16 and other aircraft (GAO 1999b).

Where did the supply problems originate? The GAO examined causes on a part-by-part basis and concluded that most problems fell into one of three categories shown in Figure 10. A significant portion of supply problems were a direct result of an Air Force Agile Logistics program that was, ironically, designed to alleviate parts problems while reducing costs. Parts inventories were cut while batch repair processes were replaced with a repair-on-demand approach. These changes were expected to save $948 million in inventory costs while maintaining or improving service levels. Parts budgets were cut in anticipation of the savings. But the savings never materialized, and service levels continued to drop. A brief history of the Agile Logistics initiative is provided in the following section.

In addressing the causes of parts problems the GAO report touched on one of the difficulties faced by the Air Force: "Because of the integrated nature of the supply system there is a general interrelationship among these causes." One manifestation of the "integrated nature" was the unintended consequences of the Agile Logistics program: less readiness for the Air Force.



	September 1997		September 1998	
Cause category	**Number**	**Percent**	**Number**	**Percent**
Forecasting and budgeting	57	36.8	0	0.0
Agile Logistics	31	20.0	26	27.1
Untimely repair	53	34.2	63	65.6
Other[a]	14	9.0	7	7.3
Total	**156**	**100.0**	**96**	**100.0**

[a] Primarily technical problems that affect the reliability of an item.

Figure 10: Causes for parts unavailability (GAO 1999b).

The Agile Logistics initiative

In 1996 the Air Force sought to improve efficiency in maintenance operations by duplicating the best practices from similar commercial operations. A group of associated changes to sustainment operations came to be called Agile Logistics. A glance at Figure 5 shows that mission capability rates dropped significantly after Agile Logistics began. A GAO report focused on how the initiative was executed in an effort to explain the drop in performance (GAO 1999a). The report complemented a 1997 study by the Air Force Inspector General.

One finding from the Air Force Inspector General's report was that numerous uncoordinated changes resulted in unanticipated negative feedback:

> Individual organizations within the Air Force implemented the initiatives without the benefit of a coordinated, Air Force-wide look at how the required changes would fit together. Such initiatives required new forms of material management discipline that material managers were not prepared to provide. Thus, a set of uncoordinated changes, each producing unforeseen problems did not achieve all of the anticipated benefits (GAO 1999a, p. 48).

Another finding was that budgets were cut in anticipation of cost savings, but the savings never materialized. Thus operations suffered from shortages of money and parts. This mismatch was due in part to inaccurate estimates of cost savings from initiatives, which were generally overstated.

Culture and leadership issues were also cited as obstacles in the change process. A passage from the GAO report describes how cultural resistance to change impeded change efforts:

> The Air Force has recognized that its corporate culture is an important factor in whether it achieves its reengineering goals. AFMC believes that changing the mindset of the current workforce will be a challenge because (1) its organizations have often found change threatening and have been unwilling to modify behavior until proposed ideas are proven, (2) the enhancement initiatives call for organizational and process changes and many personnel have difficulty understanding how they will be affected and are reluctant to embrace the initiatives, and (3) essential employee groups have not yet fully supported the implementation of the new initiatives. (GAO 1999a, p. 30)

The Air Force Inspector General concluded that change efforts would require strong leadership support that has characterized successful change in commercial firms:

> In contrast to the experience of successful commercial firms, the Air Force initiatives will not succeed unless the leadership is committed to a program of long-term, strategic, system-wide change and, without this leadership, the planned logistics changes will become a few more incremental adjustments with little effect (GAO 1999a, p. 49).

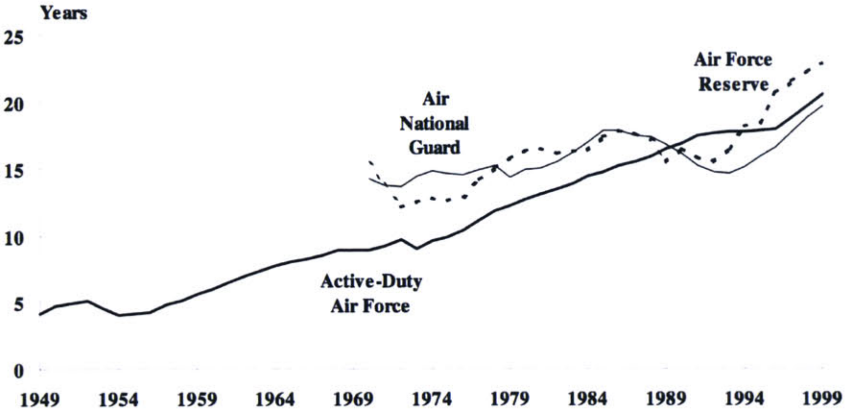
Other barriers to change included a lack of data connecting operational changes with cost savings. In many cases the relevant cost data was not collected or available to officials who were responsible for the change.

Aging aircraft and rising costs

A study by the Congressional Budget Office (CBO) addressed the "defense spending death spiral" (CBO 2001). This phrase represents a widespread belief held by defense experts and military leaders. According to one interpretation, decisions in the early 1990s to reduce purchases of new weapon systems have left the military with an aging fleet of ships, vehicles, and aircraft that are increasingly costly to maintain. The result is a self-perpetuating cycle where growing operation and maintenance costs depress the purchase of new weapon systems. Indeed, operations and maintenance costs have grown at 4% per year despite reduced flying hours and personnel numbers.

The CBO report addressed two questions: 1) does aging equipment explain the rising operation and maintenance costs, and 2) what is the relationship between age and sustainment costs? The answer to the first question is that aging weapon systems cannot account completely for the increased costs. Several other factors are at work – equipment accounts for only 20% of the operations and maintenance budget. Other rising costs come from providing healthcare to personnel, environmental cleanup costs, property maintenance, etcetera. As for the second question, the CBO concludes that O&M costs rise 1-3% per year of aircraft age (adjusted for inflation). Figure 11 shows that the average age of Air Force aircraft has steadily risen since the Korean war. This last finding has important implications to the F-16 sustainment work at the Ogden ALC. The

US Air Force is not replacing F-16s, so the fleet age will continue to grow linearly until the fighter is retired.



SOURCE: Congressional Budget Office based on data from the Department of Defense.

Figure 11: Average age of Air Force aircraft (CBO 2001).

Parts shortages hurt readiness and morale

Parts shortages can impact readiness and maintenance effectiveness, according to a report by the General Accountability Office (GAO 2001). This is one of three interesting conclusions in the report. Parts shortages impact readiness by forcing maintenance personnel to delay work and wait for parts, or cannibalize other planes for parts. Cannibalization effectively doubles the workload for maintainers because they must remove a part from another aircraft. This leads to dissatisfaction and low retention rates for maintenance technicians. According to a survey of maintainers, parts shortages were the second highest ranking cause of job dissatisfaction. The second conclusion is that parts shortages were caused by a variety of issues. A survey of Air Force item managers revealed that top causes were:

1. Higher than anticipated demand for parts.
2. Delays in repair processes due to the consolidation of repair facilities.
3. Difficulties with producing or repairing parts.
4. Reliability of spare parts.
5. Contracting issues.

The second item warrants further discussion: in 1996 two of the five air logistics centers were closed in the Base Realignment and Closure (BRAC) process, resulting in significant consolidation into the three facilities that exist today. There was still considerable disruption at the time this report was published in 2001.

Improvement programs face implementation challenges

Persistent reports of parts shortages throughout Air Force sustainment operations resulted in another recent GAO study (GAO 2003a). Significant findings were that the Air Force had adequate plans to address parts issues, but implementation needed to improve. One interesting finding was that the maintenance organization had started all of the 24 improvement parts-related initiatives identified in 2001 while the supply organization started only 7 of 19. The author offers an explanation for this disparity in section 4.3.3.

Implementation-related findings in the report depict an organization that is struggling with improvement projects. Researchers concluded, "most initiatives lacked output-related performance measures and targets". In other words, the initiatives were not linked to performance metrics that were relevant to stakeholders. Furthermore, the Air Force did not apply the results of a completed initiative related to setting budgets for spare parts. The Air Force requested $5.3 billion for spare parts in 2004 despite their own analyses predicting a $5.9 billion requirement. Later the Secretary of the Air Force reported a $578 million shortfall in spare parts funding, which is approximately equal to the difference in the projected and requested totals.

Management issues contributed to implementation difficulties as well. A 2002 study from an Air Force review team consisting of retired generals and senior executives concluded that transformation efforts had a high risk of failure because 1) the Air Force is not clearly articulating the need for change throughout the service, 2) top-level commitment to initiatives is not strong enough as evidenced by schedule slippage and funding difficulties, and 3) clear roles and responsibilities have not been set across initiatives.

Sustainment funding is complicated by Air Force policy

Air Force depots charge fees to operational units for depot work, not unlike a corporation. Depot fees almost doubled from 2000 to 2004. The average price for depot work rose from $119.99 per hour to $237.84. A GAO report sought to determine 1) why prices increased, 2) if prices charged recovered the cost of work, and 3) if the Air Force has taken steps to improve efficiency and reduce costs (GAO 2004). An increase in material costs accounted for about 67% of the overall price increase. However, the Air Force has not completed an analysis of materials expenditures so it cannot quantify the extent of increase from individual sources.

The report revealed several interesting practices around pricing. For example, the Air Force had intentionally set depot fees below the actual cost of work from 2000-2003. This practice was designed to ensure that customers could get necessary work completed with the amount of funding available to them under the budget process. In 2004 the Air Force policies changed to more closely align prices with the cost of work. Finally, the report states that the Air Force depots are not controlling costs effectively because there is no methodology for doing so, and a database for sharing cost savings information between ALCs has gone unused. The report also mentions that the working capital fund (WCF) that supports maintenance activity was over funded by $1.3 billion, and that congress and the Air Force would be examining alternative uses for the excess funds.

Conclusions from the oversight reports

Several impressions are left by the oversight literature; together these impressions form a picture of an enterprise that is not meeting stakeholder expectations. Continued scrutiny from the CBO and GAO demonstrates that congress is not satisfied that taxpayer resources are being used effectively. Another impression is that efforts to improve sustainment are progressing slowly, if at all. Some improvement efforts have created unintended consequences that overpower the intended benefits. This is due to the sustainment operation's complicated, integrated nature, and to improvement initiatives that have not been implemented effectively due to low leadership support and a lack of measurable goals. Policy interactions add another layer of complexity to the sustainment enterprise. At times the results of analyses have been overlooked in favor of Air Force policy considerations. Aging aircraft will make sustainment more difficult over time. Finally, there is a lack of a system perspective in which interrelated objectives (high readiness, low sustainment costs, low inventory levels, etcetera) are traded off. Indeed, a GAO report found that the Department of Defense does not have a clear, defined process for setting aircraft availability goals which drive these objectives (GAO 2003b).

2.2.2 Academic and analysis work

Universities and the Air Force have generated a substantial number of studies related to Air Force sustainment. Perhaps the most significant distinction between these studies and the oversight reports is the scope of analysis. Oversight reports are narrowly scoped to the effective use of taxpayer dollars. Other work may be motivated by a wider variety of considerations. The following sections present several academic and analysis reports that are relevant to change efforts at the Ogden ALC.

Forecasting mission capability rates and identifying influences

The mission capability rate is perhaps the most widespread measure of the Air Force sustainment operation's performance. This rate measures the fraction of time, on average, that an aircraft is available for a mission. A study conducted by Air Force personnel (Oliver 2001) examined how the Air Force forecasts capability rates. An improved forecasting method was proposed. The authors focused on the F-16C/D variant throughout the study.

Capability forecasts are important for two reasons. First, they are used in a variety of decisions throughout the Air Force related to allocating resources. Therefore forecasts should be as accurate as possible. Second, forecasts may be used as a tool to understand and influence mission capability. Current Air

Force forecasting techniques are quite accurate, but they are projections based on trends and funding levels that offer little insight into causal relationships. Causality is useful to those who seek to influence capability rates.

Mission capability rates are influenced by a broad array of factors ranging from maintenance funding levels to whether pilots are flying aggressively with high-speed maneuvers that put great stresses on an aircraft. The multitude of influences was arranged into six categories.

- Personnel factors relate mostly to the skill level, experience, and quantity of maintainers.
- Environment factors include the aircraft age, mission, and overall operational tempo of the Air Force.
- Reliability and maintainability is influenced by component failure rates, cannibalization, etc.
- Funding can be disaggregated into levels for spare parts, contractor logistics, operations, and the like.
- Aircraft operations refer to utilization rates, the number of missions, etc.
- Logistics operations is related to base cycle repair times, parts inventory levels, etc.

Potential influences for each of the categories are listed in Figure 12. The authors used regression techniques to identify the factors that had the strongest link to availability. Data from four categories went into the analysis: personnel, reliability and maintainability, funding, and logistics operations. Environment and aircraft operations factors were excluded because of the difficulty in obtaining data and quantifying these factors. Of all the remaining influences, seven accounted for 95% of the variation in mission capability rates:

- TNMCM (total not mission capable due to maintenance) hours, a measure of the time it takes maintainers to make an aircraft operational. This measure does not include time spent waiting for parts.
- Cannibalization hours – the time spent removing parts from a not-mission-capable aircraft and replacing the parts on another aircraft.

- Average aircraft inventories.
- Four additional factors related to the quantity and experience levels of maintainers.

Using these factors as inputs for a regression model result in a prediction error rate of 1.9% when forecasting 7 quarters ahead.

These results must be interpreted with care. For example, concluding that factors not on the list are unimportant would be a serious mistake. A glance at Figure 13 suggests that mission capability is very closely tied to obligation authority (sustainment budgets): one curve unmistakably follows the other. Yet budgets are not among the top seven factors. What the regression analysis provides is the fewest number of parameters that account for 95% of the mission capability rate. A parameter that is not on the list, like budgets, can certainly affect the capability rate, but it does so less directly than other factors that are on the list.

What is remarkable about these seven factors is that *none of them are directly controlled by the Air Logistics Centers.* However, this observation should not be construed to mean that the ALCs have no control over mission capability. What it does suggest is that sustainment performance is affected by a wide variety of interrelated factors, and that the ALCs influence on mission capability should not be considered in isolation but rather as a part of the overall sustainment system.

Personnel	Environment	Reliability & Maintainability	Funding	Aircraft Operations	Logistics Operations
Personnel assigned or authorized	OPSTEMPO factors	TNMCM hours	Replenishment spares funding	Aircraft utilization rates	TNMCS hours
Personnel in each skill-level (1, 3, 5, 7, 9 and 0)	PERSTEMPO factors	Maintenance downtime/reliability	Repair funding	Possessed hours	Base repair cycle time
Personnel in each grade (E1-E9)	Number of deployments	Mean time between failures/mean time to repair	General support funding	Average sortie duration	Order and ship time
F-16 maintenance personnel in various Air Force specialty codes (AFSC)	Policy changes	Code 3 breaks	Contractor logistics support funding	Flying hours	Level of serviceable inventory
F-16 maintenance personnel by skill-level per AFSC	Contingencies	8-hour fix rate	Mission support funding	Sorties	Level of unserviceable inventory
F-16 maintenance personnel by grade per AFSC	Vanishing Vendors	Reparable item failures	O&M funding	Flying scheduling effectiveness	Supply reliability
Retention rates for F-16 maintenance personnel	Weather	Cannibalization hours/actions	Initial spares funding	Type mission (DACT, CAP, and so forth)	Supply downtime
Personnel per aircraft ratios	Aircraft age	Repair actions/hours	Acquisition logistics funding	Over-Gs	Depot repair cycle time
Maintenance officers assigned or authorized	Aircraft mission (training, test, combat)	Maintenance man-hours		Airframe hours	Maintenance scheduling effectiveness

Figure 12: Influences on aircraft mission capability rates (Oliver 2001).

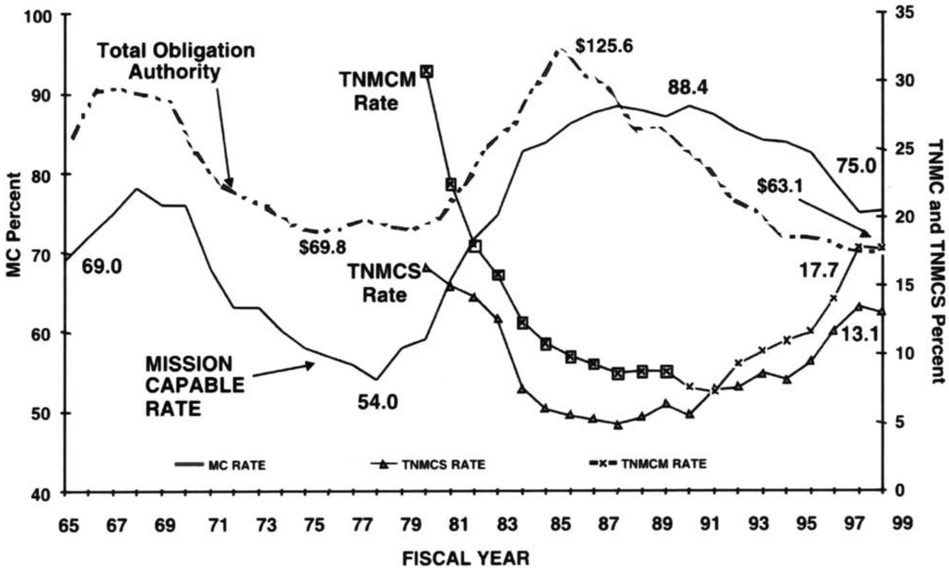


Figure 13: Air Force fighter mission capability rates and sustainment budgets (obligation authority) (Oliver 2001).

Barriers to improvement

A graduate thesis focused on barriers to ending wasteful practices within the Air Force sustainment of F-16 avionics (Brandt 2003). The author first identified wasteful practices by applying a lean methodology and value stream mapping. This process lead to four overarching conclusions about avionics sustainment:

1. There is considerable waste in the system.
2. The system has lost its customer focus.
3. There is considerable negative impact from not having spare parts available for end-item repair.
4. The lack of information quality and visibility is impeding the flow necessary to support a lean enterprise.

Brandt describes a variety of behaviors and practices that support these conclusions. For example, work is prioritized with a focus on lagging indicators (e.g. mission capability rates and backorders) and internal budget constraints. This practice practically guarantees that workers will always be "fire fighting" the latest parts issue instead of proactively addressing demand as it arises. Brandt recommends prioritizing work based on actual demand data from the field - a practice that is customer-focused.

Taken together these four conclusions depict an operation that may be difficult to change. Some of the basic building blocks needed for improvement, like high-quality information, are missing. The lack of customer focus may translate into reduced motivation to improve the system and address waste.

Tradeoffs in Air Force sustainment

Another thesis focused on the tradeoffs between parts inventories, aircraft squadron sizes, and cannibalization policy (Tsuji 1999). A variety of factors were simulated in a model: parts inventories, cannibalization levels, depot repair times, squadron sizes, etc. What is the optimal mix of these factors? The answer is complicated, as it is with many questions about sustainment. Tsuji found that the lowest overall cost to the Air Force was achieved with small squadron sizes and relatively high levels of spare parts. But this answer carried a caveat: small squadron sizes reduce the ability to respond to surges in demand for aircraft, surges that may be related to war or other events of critical importance. Tsuji summarized his observations from the analysis as follows:

> Perhaps the key point of this thesis is that it is important to consider the systemic effects of decisions and changes in the Air Force. Making decisions that seem to be beneficial on a local scale may in fact be detrimental to the overall system. Well-meaning individuals or organizations may act in a counterproductive manner if they are not aware of their impact on the system. Furthermore, if performance metrics are not established with overall system performance in mind, individuals and organizations may actually be guided to act counterproductively. Understanding systemic behavior and the impact of decisions on the overall system is crucial.

Tsuji examined several factors that are controlled by the ALCs. For example, depot repair time and spare parts levels had a significant impact on availability levels. Figure 14 shows that high availability levels require low repair times at depots and significant levels of spare parts. The tradeoff between parts inventories and mission capability explains the drop in mission capable rates following the Agile Logistics program. Inventories were cut, but depot repair times were not reduced, so mission capability rates fell.

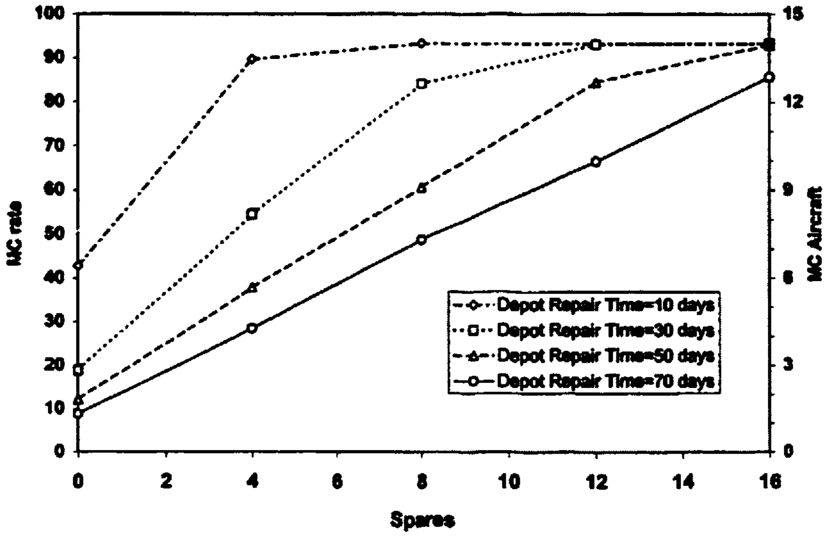


Figure 14: The impact of spare parts inventories and depot repair time on mission capability rates (Tsuji 1999).

Conclusions from academic and analysis work

The academic and analysis work provides techniques for understanding and influencing sustainment operations. Understanding was built along two dimensions. First, sustainment operation interactions were described and predicted using simulation and regression analysis techniques. Second, lean methods were applied in an effort to identify barriers to improving performance. Together these findings will be useful for addressing some of the problems identified in the oversight literature.

3 Change at the Ogden Air Logistics Center

This thesis endeavors to show that a particular approach to change is well suited to complex enterprises such as the Ogden Air Logistics Center. Questions naturally arise from such a contention. Namely, how does the ALC execute change now? Are there examples of successful initiatives? What are the change capabilities and barriers in the organization? The following sections address these questions.

The author observed change processes at the Ogden ALC over the course of six visits and numerous interviews and meetings. The following sections present these observations with an emphasis on three topics: 1) sustainment operation performance at the ALC, 2) methods for improving performance, and 3) change capabilities and barriers at the ALC. These observations provide a foundation for the analysis and recommendations in the following section.

Many of the observations were made in the context of Enterprise Value Stream Mapping and Analysis (EVSMA), a process that began at the ALC at the end of 2003 and concluded in August of 2004. Facilitators from the Lean Aerospace Initiative consortium joined a team of 12 leaders from the ALC in a process designed to enable and drive lean transformation at an enterprise level. Outcomes from the EVSMA process are described in the following section.

3.1 Change processes

How does change happen at the ALC? Who initiates it? How are change efforts supported? These questions can be addressed by examining change efforts, past and present. It is useful to place the answers into the context of a process for change, a model that describes how workers and leaders at the ALC conceptualize and execute change processes.

3.1.1 Examples of change

Most of the change success stories emerging from the ALC come from the Maintenance Wing where lean improvements have been ongoing since the late 1990s. In 2003, for example, the maintenance wings at all ALCs had 64 initiatives identified versus 20 initiatives for logistics operations at the centers (GAO 2003a, p. 8). The change process in the Maintenance Wing starts with leadership identifying a particular maintenance line or shop for improvements, such as the generator shop or F-16 upgrade line in the depot. The initiative's focus may be motivated by input from Air Force leadership through higher-level organizations such as the Depot Maintenance Activity Group or Supply Management Activity Group, which are, in turn, influenced by sustainment customers (operational aircraft commands) and higher levels within the Air Force and Congress. Some members of Congress are keenly aware of sustainment performance, if the volume of reports from the General Accountability Office and Congressional Budget Office are any indication. There are 425 reports from the GAO containing the phrase "Air Force" and the word "sustainment" as of May 2005.

Once a line or shop is identified the Maintenance Wing has typically hired outside consultants for change leadership, facilitation, and expertise. The Maintenance Wing leader, Brigadier General McMahon, described the organization's approach: "The [Maintenance Wing's] model for facilitators is to bring in experienced outsiders to help insiders. Those who are interested and motivated will rise to the occasion and become the next facilitators."

McMahon's comment alludes to a goal within the organization: to develop insiders to lead the next round of improvements.

Experienced internal change leaders are beginning to spread across the ALC. For example, the current director of the ALC Transformation Directorate had experience with improvement initiatives in his previous position with the Maintenance Wing. Indeed, the very existence of the Transformation Directorate, established in 2003, is due to the growing number of improvement initiatives happening across the ALC and the need to coordinate them. Lean events are active in 65 areas at the center (CTPID 2004).

Another feature of the ALC change process is openness. No single "brand" of improvement methodology is advocated. Other organizations, such as Raytheon, have successfully taken the opposite approach by requiring all initiatives to use the same methods (Hemann 2004). In an interview the author asked McMahon if there were any difficulties with using multiple methodologies. His response indicates a model of change that is similar to a marketplace:

> [The Maintenance Wing] has multiple approaches to change. That isn't necessarily bad, and there doesn't have to be tension between methods. As long as there is a closed loop then the best methods will rise to the top and be copied by others. Synthesis occurs over time. Our experience has been that more integration leads to more success.

The reference to a "closed loop" alludes to monitoring feedback from change programs and using it to improve future efforts.

Some leaders within the Maintenance Wing appreciate the flexibility inherent in an open model. For example, one manager explained that an improvement program, if it were pushed from the top, would have met a backlash from lower-level organizations. He added, "Thank goodness there was no one in an ivory tower telling us how to do lean."

3.1.2 Enterprise Value Stream Mapping and Analysis

In December 2003 twelve leaders at the ALC embarked on an enterprise-level planning effort that concluded in August 2004. The process, called Enterprise Value Stream Mapping and Analysis (EVSMA), follows a sequence shown in Figure 15. EVSMA, according to the ALC commander General Sullivan, is "... a mechanism for getting to that strategic look at how you are going to deploy lean across the enterprise" (CTPID 2004).

The eight-step EVSMA process has four phases. The "Data Collection" phase covers steps two through four, it is designed to identify enterprise stakeholders (e.g. combat units that fly F-16s), set high-level objectives, and map processes that deliver value to stakeholders. The "Current State and Future State Visioning" phase consists of steps five through seven. In this phase leaders map and evaluate interactions between parts of the enterprise, evaluate how well the enterprise is meeting stakeholder expectations, and define goals for the future. Step seven of EVSMA resulted in the goals shown in Figure 16. Leaders want to reach these goals within 10 years. Step eight of EVSMA is the improvement plan, in which seven high-level projects were sponsored. One of these projects was to increase F-16 system availability in accordance with the goals from Figure 16. System availability for the F-16 is approximately 70% (USAF 2005); leaders want to increase this measure to 90%.

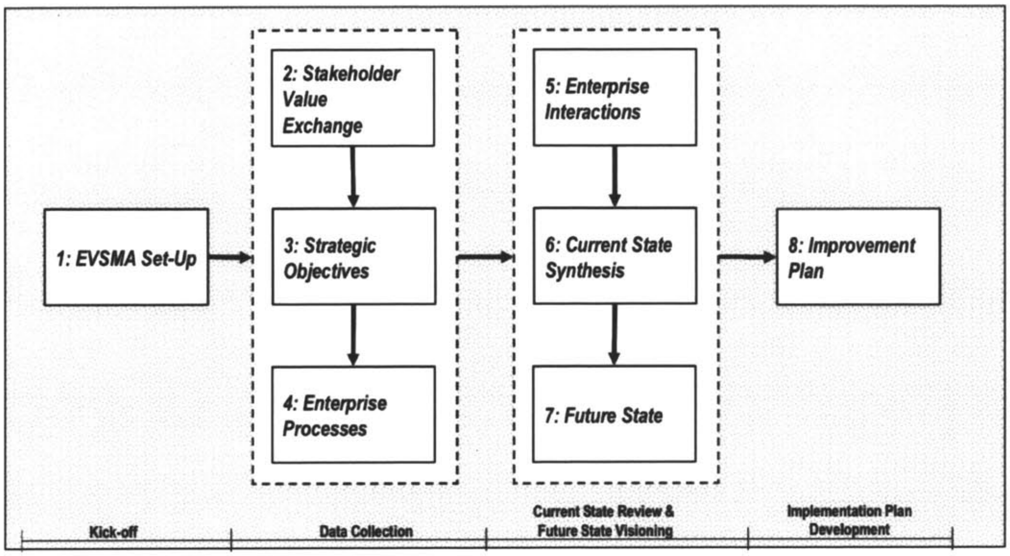


Figure 15: Enterprise Value Stream Mapping and Analysis process overview (Christopherson 2005, p. 6).

- Support system availability at 90% or better. System availability is defined as the number of available items (jets, avionics assemblies, etc.) divided by the total number of items.
- Reduce flow time by 50%. Flow time measures how long an item (jet, avionics assembly, etc.) is under ALC control, from induction to sale.
- Support readiness at 100%.
- Reduce costs by 25%.

Figure 16: Improvement goals established at the Air Logistics Center.

While leaders participated in EVSMA a parallel training program commenced for eleven civil servants from the ALC. A Raytheon employee with experience in improvement initiatives trained the team, called "Black Belts" in Center parlance, to act as change agents by analyzing data, identifying opportunities for improvements, and leading change efforts. The Black Belt training curriculum is shown in Figure 17.

Many topics in the curriculum have roots in manufacturing. For example, statistical process control tools are often used to monitor quality and detect manufacturing problems. Quality function deployment was designed to aid product development in Japanese shipyards. Theory of constraints was introduced in the context of manufacturing lines, as was 6 Sigma. In each of these cases the problem boundaries are defined as a single manufacturing operation or product. Design of experiments techniques depend on controlled conditions that may be difficult to impose in large-scale operations.

Skill category	**Topic**
Lean	Process mapping Value stream mapping Visual Controls 6 Sigma Workplace organization
Statistics	Statistical process control Cause and effect diagrams Design of experiments Quality function deployment Pareto charts
Theory of constraints	Critical chain
Organizations and leadership	Leading change Integrated supply chain Support and enabling processes

Figure 17: Training curriculum for 11 enterprise change agents at the ALC.

The envisioned enterprise change model was that the Black Belts would use their new skills to develop a portfolio of improvement projects designed to improve F-16 system availability, and then leaders would choose and support projects from the portfolio. But when this process was carried out the leaders decided that the proposed projects, if executed, were not going to result in the magnitude of improvement they sought. The black belts were eventually integrated into other improvement initiatives that had been ongoing at the ALC before and during EVSMA.

Why did the proposed projects not meet leadership expectations? One possible contributing factor, which will be developed by the author in section 4.4, is that the Black Belts were using the wrong tools for the job. They were given a problem with high dynamic and behavioral complexity (as evidenced in section 2.2) along with a toolset designed for process improvements on the scale of a single factory or production line.

Business Diagnostic

One step of EVSMA was to perform a business diagnostic (USAF 2004) intended to identify targets for improvement. The diagnostic was conducted at an enterprise level, with "enterprise" taken to mean all of the activities conducted at the facility in Ogden, Utah. One finding was that F-16 depot maintenance operating expenses dominate costs at the ALC - it is the single largest operating expenditure by a factor of two at least, representing roughly 30% of total ALC operating expenses. However, logistics organizations at the ALC manage parts worth hundreds of millions of dollars, but these "flow through" costs are not included in ALC operating expenses. Similarly, the manpower dedicated to F-16 depot maintenance is greater than any other division by a factor of two at least.

Another finding was that F-16 system availability was approximately 70%. Other parts of the ALC, such as ICBM operations, had availability greater than 90%. A clear picture emerges when system availability is combined with the findings about F-16 operations dominating costs: Improving F-16 operations has the most potential to impact cost, flow time, and availability goals at the ALC. Other programs, such as the A-10 aircraft, are a significantly smaller part of ALC operations.

The business diagnostic includes an "F-16 unavailability analysis", which shows that unavailable aircraft fit approximately equally into three categories: waiting for parts (TNMCS), waiting for maintenance manpower, facilities, or equipement (NMCM), or undergoing maintenance. Data from 2003 and 2004 were compared, which showed that F-16s in the depot were reduced in 2004.

However, the reduction was absorbed in other categories of unavailable aircraft leaving system availability unchanged, which was highlighted in the presentation. Three recommendations were given:

1. Conduct a business diagnostic on F-16 supply. Supply was chosen because it impacts a high number of planes, and it influences the other categories of unavailable aircraft.
2. Conduct a business diagnostic on maintenance later. This diagnostic would focus on the interrelationships between F-16 program management and aircraft awaiting maintenance (NMCM).
3. Leverage ongoing improvements in the F-16 depot maintenance operations. Lean improvement initiatives have been underway at the depot since the late 1990's.

The first recommendation became known as the F-16 supply diagnostic. The maintenance diagnostic had not begun as of February 2005.

F-16 supply diagnostic

Improvement efforts related to F-16 supply at the ALC had been ongoing when EVSMA began. Over the summer of 2004 the Black Belts were integrated into the existing efforts. Results from the F-16 supply diagnostic were presented to leaders in October of 2004 (Hardy 2004). The overall approach to the diagnostic was to collect and analyze data, categorize the root causes of unavailable aircraft awaiting parts, and then chooses three to five targets of opportunity for improvement efforts. Quality Function Deployment (QFD) methods were used to rank the causes of unavailable parts for F-16s. Three targets were identified from the analysis:

1. Improve parts forecasting accuracy.
2. Improve the production of subassemblies that are often the cause of F-16 unavailability, such as the radar antenna.
3. Perform "proactive leveling" to set consumable supply inventories at the base or unit level by using global data to forecast parts demand instead of base-level local data.

A second independent analysis was performed on F-16 supply issues (Christopherson 2005). This work resulted in conclusions that were similar to Keller's. Christopherson focused on reducing cycle time in the F-16 radar antenna shop. Failures of the F-16 radar antenna are consistently a top cause of unavailability.

Change coordination

Observations of change practices at the ALC have not revealed a structured approach to managing the interactions between change initiatives. Leaders are certainly aware of interactions between parts of the sustainment system (these relationships were mentioned explicitly in the ALC business diagnostic), but no attempts to quantify or model the interactions are evident. A de facto change management process emerges in which initiatives are executed independently with little emphasis given to influences on other parts of the sustainment operations that may occur outside the ALC. The mental model implicit in this method is that changing the ALC can be decomposed into independent improvement initiatives. The following section describes a handful of initiatives at the ALC.

3.2 Islands of success

The impression left by the oversight reports from section 2.2.1 is that sustainment operations are not improving. This impression is not entirely accurate. Significant improvements have been made to parts of the organization. Lean improvement initiatives began in the late 1990s and are active in approximately 65 areas at the ALC (CTPID 2004). A few examples are given below (Keller 2005).

- An F-16 depot upgrade program valued at over $1 billion implemented a cellular flow line and achieved significant improvements. Flow days dropped from 142 to 125, tows (the number of time an aircraft has to be moved) dropped from 21 to 12, and on-time delivery rose from 93% to 100%.
- A lean project in the F-16 wing shop resulted in flow days dropping from 64 to 32, while overtime, costs, and complaints dropped as well.
- An initiative in the gearbox shop has reduced flow days from 90 to 52 days, work in process has dropped from 46 assemblies to 21, and labor hours have dropped from 236 hours per gearbox to 68. Annual direct labor costs are expected to drop by $5 million.

These improvements fall under the definition of "islands of success", a term coined by researchers examining lean improvement programs in the aerospace industry (Murman 2002, p.117). Each of the improvements described above are within the boundaries of a single shop or organization. However, isolated improvements may not result in systemic improvement (such as increased system availability) if the efforts are not coordinated, a problem that hindered past improvement efforts at ALCs (GAO 1999a, p. 48).

A handful of cross-organizational initiatives have emerged at the ALC. One example developed in response to a persistent problem: parts availability. Workers in a maintenance shop were often unable to make repairs because they did not have enough spare parts. In many cases there were enough parts on the base, but they were not on-hand when the workers needed them. Some workers responded by hoarding parts at their workstations. This practice may seem to improve the situation for hoarders, but the benefits may be mitigated by undesirable side effects like less accurate inventory forecasting and less trust from the logistics organization that issues parts. A new inventory system was put in place where workers draw parts from point-of-use bins - a kanban in lean parlance. Other workers fill the bins at regular intervals. Thus the control of parts was shifted from the logistics organization to the maintenance organization. The logistics organization was extremely reluctant to give up control - a "major effort" was required to overcome concerns that parts would be stolen.

What is encouraging about this example is that a problem stemming from a lack of coordination between organizations was recognized and treated. What is discouraging is the amount of effort required to build a bridge across two organizations that 1) are located on the same base, 2) are at relatively low levels that presumably require less authority to change, and 3) share the same leaders at higher levels in the organization. If these three conditions are not met - if the ALC must coordinate with an external supplier, for example - then will the change process be even more complicated? Difficulties such as these point to the challenges inherent with linking islands of success.

3.3 Complexity

Sustaining Air Force jets across the globe is a complicated problem by practically any measure. Consider the challenge faced by those who want to improve sustainment opertions - where do they begin? The Vice Commander at the ALC, Colonel McCasland, described the difficulties associated with quantifying improvements: "Auditable, quantitative trails seem to evaporate. Moving the analysis up to higher levels of the organization seems to result in losing a grasp on quantitative performance measures." Why is analysis so difficult? The large number of organizations and the complicated interactions between them act as a barrier to analysis and understanding.

Some analysis methods, such as value stream mapping (VSM), have yielded valuable insights for organizations that are much simpler than an ALC. When VSM is applied to a complex organization like the ALC then does it still provide insight? One leader at the ALC was skeptical: "A value stream map of a large enterprise like the ALC requires high granularity. Is that useful? Can you VSM the entire air force? What does that tell you?" This response suggests that the VSM of the entire Air Logistics Center did not produce the intended insights for at least one EVSMA participant. Another participant indicated the difficulty with analyzing the ALC as a whole when he said, "Getting our arms around the ALC enterprise has been slipperier than we thought."

Organizational complexity is exacerbated when organizations have different priorities. Indeed, an EVSMA exercise designed to emphasize the interrelatedness of organizations resulted in the opposite conclusion for one participant, who said: "What came out of EVSMA was that there are four separate units at the base with different goals." For example, the supply organization is often measured by supply effectiveness, which is the fraction of time that a part is available when it is needed. The Defense Department acknowledges that current policies "... are generally biased towards the purchase of low cost/high-demand items versus those critical spare parts that would most improve mission capable rates" (GAO 2003a, p15). Purchasing low cost / high-demand parts maximizes supply effectiveness, which is good for the supply organization, but it hinders aircraft availability. This example illustrates how organizational complexity and miss-aligned goals can result in lower performance.

An additional layer of complexity is introduced when multiple changes are executed at the same time. The ALC is currently undergoing "the most turbulent time we can recall," according to several veterans with over twenty years at Ogden. Indeed, approximately 65 lean initiatives are active at the base (CTPID 2004). Changes at the base level are complemented by changes at higher levels. The Vice Commander at the ALC, Colonel McCasland, described 2005 as "a volatile year in the Department of Defense." Major changes are expected to come from the wing reorganization (which all ALCs underwent), the Quadrennial Defense Review, and the Base Realignment and Closure (BRAC) process. As the name implies, BRAC could potentially result in the realignment or closure of the Ogden ALC. Preliminary BRAC results announced in May 2005 indicate that the ALC will lose 423 civilian positions and gain 278 military (DoD 2005).

3.4 Non-market forces

"The Air Force cannot do things that a corporation can do, like prioritize or do marketing. The Air Force is not a market-driven organization." This statement from a leader at the Center points to an important distinction between the ALC and a corporation. A variety of non-market constraints are imposed on the Center. The comment about prioritization points to the fact that the ALC must accept work from the Air Force, no matter how onerous or under funded the work may be. Contrast this with corporations that can leave markets if conditions are not favorable.

Workforce practices represent another non-market force. Suppose that leaders at the ALC wanted to cut costs by reducing the workforce. Doing so would be extremely difficult. One Air Force official recalled that a proposal to temporarily furlough workers at the ALC resulted in a phone call from a concerned Congressional representative. Indeed, the ALC is the largest employer in Utah with approximately 13,000 workers and a payroll over half a billion dollars (GlobalSecurity.org 2002). Workforce reductions would be resisted by a variety of constituencies including local businesses and governments. Strong resistance is a frequent response to base realignments and closures (Cahlink 2004).

Workforce practices within the Air Force may devalue the efficient use of labor. For example, a database of improvement initiatives did not include metrics related to the amount of labor hours invested. When asked about this omission, an Air Force officer explained that the service did not view labor hours in that context. He added, "According to the Air Force I'm free." However, a counterexample to this view was provided by a leader who explained that a fixed number of people were assigned to his organization. His objective was to make the best use of that number, a view that emphasizes efficiency.

Non-market forces influence improvement efforts at the ALC by constraining solutions and flexibility. If efficiency is improved and costs are reduced, for example, regulations may prevent the savings from being reinvested into more improvements. Funding levels are closely monitored, which prevents the ALC from building up a financial surplus. One example of this oversight pressure occurred in 2003 when Congress criticized the depots for having excess funds (GAO 2004). Section 3.6 provides more information about funding constraints at the ALC.

A discussion about market and non-market forces within the Air Force raises several questions: should the Air Force emulate corporations? How should the Air Force measure value when profit is prohibited? Leaders in sustainment operations are keenly aware of such questions. The commander of the Maintenance Wing, Brigadier General McMahon, summarized his view when he said, "Some people in the Air Force worry about becoming too business-like. But I do not see that as a negative result if readiness is the goal instead of profit."

3.5 Leadership turnover

In December 2003 a group of twelve leaders at the Ogden ALC began the EVSMA process. By the time the exercise concluded in August 2004 approximately half of the leaders had changed, an annualized turnover rate of 67%. Frequent rotations are a fact of life in the Air Force. According to one leader, "Air Force culture is to take the hill, plant your flag, and move on." In other words, sustained effort on long-term problems or change is not emphasized. An officer in a new position who expects to move on within two years may have little incentive to engage problems that cannot be addressed on a timescale measured in quarters.

Major General Sullivan, who assumed command of the ALC in July 2003, spent his first 75 days "... looking at my center before I set a direction for the organization" (CTPID 2004). If leaders of complex organizations do not take the time to learn then they risk misunderstanding their challenges, making matters worse, and not understanding their effect. In a humorously titled paper, "Unskilled and Unaware of It: How Difficulties in Recognizing One's Own Incompetence Lead to Inflated Self-Assessments", Kruger et al. established that people who are unskilled suffer a dual burden: they make erroneous decisions, and they lack the meta-cognitive ability to realize it (Kruger 1999). This problem afflicts people of all abilities because the term "unskilled" is highly contextual. Clever, hard-working people can be unskilled in certain domains - the moniker should not imply stupidity or laziness. Thus leaders at the ALC who take on complicated problems may have to dedicate their time to understanding and learning before they take action. Indeed, 75 days is 10% of a two-year tenure.

3.6 The color of money within the Air Force

The "color of money" refers to restrictions on how money is used. For example, the Sustainment Wing at the ALC may receive dollars for parts (call these purple) and dollars to pay worker salaries (call these silver). Parts of the ALC are prohibited, by law, from using the funds for other purposes. Silver money cannot pay for parts, no matter how under funded the purple account is. The governing laws are sufficiently complicated that an Air Force Captain at the ALC was going to "learn about all the colors of Air Force money" over a six-month rotation focused exclusively on this topic.

Purple, silver, and other colors are apportioned in a budgeting process called the Programming, Planning, and Budgeting System (PPBS). Some researchers contend that PPBS, which was enacted in the 1960's, has formed "a defense establishment culture that embodied inflexibility, bureaucratic complexity, and risk-averse behavior" (Murman 2002, p42). During a meeting in January of 2005 the Vice Commander at the ALC, Colonel McCasland, described the process:

> Currently [the Defense Department is] finishing their fiscal year 2007 budget. Fiscal year 2006 is being approved higher up the chain, and Fiscal year 2005 is already written into law. PPBS has a three to four year lag. Since funds are appropriated they have specific uses prescribed. For example, parts money cannot be shifted to other areas of need. Money saved cannot necessarily be reinvested in the organization or returned to the customer.

This description carries at least three critical pieces of information. First, there is a long delay between when funds are allocated and when they are spent. Projections are used to anticipate the demand and set budgets. But the projections may not match the real demand three to four years in the future. For example, the number one cause of parts shortages for F-16 engines in 2000 was projections that were lower than actual demand (GAO 2001, p15).

The second point from this statement is that money cannot be shifted between funds. This practice can cause operational problems because overall effectiveness will be limited by the worst-performing segment of the sustainment operation. Consider an example where parts budgets are under funded while labor budgets have excess funds, relative to demand. If money is unrestricted then operational penalties can be reduced by shifting money between funds. The worst-performing segment can be mitigated. Conversely, color of money restrictions prevent this rebalancing.

The third point focuses on the last part of McCasland's statement, that money saved cannot be re-invested. This statement does not apply to the entire ALC. The Maintenance Wing uses a Working Capital Fund. Unlike other wings at the ALC that receive appropriated, colored funds through Congress, the Maintenance Wing is paid by other organizations to fix jets and components. However, once the money goes into the Wing's Working Capital Fund it loses its color. McCasland elaborated on this point when he compared appropriated, colored money with the Working Capital Fund: "Contrast this with the Maintenance Wing, which can make short-term investments because its money is more fungible. [The Maintenance Wing] charges customers for sales into the WCF, which is set up to allow operations more like a business."

The Maintenance Wing's improvement efforts are significantly more advanced than efforts at other divisions in the ALC. Could this difference have anything to do with the Maintenance Wing having more spending flexibility? The answer is yes according to the commander of the Maintenance Wing, Brigadier General McMahon. When asked about the disparity he attributed the performance difference to three factors: 1) the nature of work performed within each organization, 2) more spending flexibility within the maintenance wing, and 3) the maintenance wing leadership's personal investment in lean and their willingness to take risks.

Points 1 and 3 will be addressed in section 4.3.3, but for now the focus is on point 2, that spending flexibility aids improvement efforts. The Working

Capital Fund provides enough leeway for the Maintenance Wing to make improvements, reduce costs, and then re-invest the savings in more improvements. Re-investment creates a self-sustaining feedback loop that supports continual improvement. Indeed, a study of improvement efforts, both successes and failures, found that a key distinction between them was re-investment and the creation of self-sustaining positive feedback (Keating 1999).

Another difficulty arising from the budgeting process is that organizations have little incentive to make investments that benefit all organizations. A RAND report described how the disincentives arise:

> [Air Force programming policy] makes the PPBS process feel like a zero-sum game. Each player looks for a way to extract whatever it can, from beyond its assigned budget constraint, to support its program. In such a setting, it is natural to expect an operating command to look for a free ride on the investments it hopes others will make in the common assets that build scale economies. Unfortunately, no one has an incentive to invest. It is natural for operating commands and AFMC to point fingers at each other, seeking to induce the other party to invest to improve its own performance... The result is the Air Force has a great deal of difficulty achieving consensus on an internally consistent plan of PPBS roles and responsibilities... Investments in spares, test stands, and central control mechanisms that could benefit many players simultaneously are particularly at risk. (Camm 2003, p 39)

Camm has described a 'tragedy of the commons' in which there is incentive to take as much as possible from the system, but there is no incentive to make improvements that benefit all.

3.7 Compliance culture

During a tour of maintenance shops at the ALC the tour guide described the last week's activities - inspections - with a note of frustration in his voice. Work had stopped completely to allow a government-mandated weeklong inspection at the facility. Auditors interviewed shop workers, and their questions were focused solely on regulatory compliance. According to a manager, "No one ever asks if your performance is good, just if you're complying with regulations."

"Compliance culture" is a term coined by a veteran civil servant at the Ogden ALC. The phrase grew from his experience with improvement projects within several maintenance shops. Compliance culture is characterized by an inward-looking perspective. Satisfying the demands of the bureaucracy override other considerations like customer needs or value. An example of compliance culture in action can be found in certain government promotion practices where civil servants may be placed in charge of improvement initiatives based on their seniority without regard to ability.

This inspection example suggests how compliance culture is supported at the ALC. Compliance culture may be a response to the oversight pressures that are attached to government funding. One leader underscored the pressures when he said, "The Air Force is constantly tracked and monitored." Oversight often focuses on micromanaging costs in such a way that de-emphasizes value to the customer (Murman 2002, p.82). Complying with the regulations can be onerous, which is why some companies (e.g. Pratt and Whitney) minimize the negative impacts by maintaining separate divisions for government and commercial work.

Compliance culture is inherently incompatible with lean culture, which has been characterized as a "community of scientists" (Spear 1999). Lean culture emphasizes strong ties to customers and a continual improvement process based on data-driven experimentation. These two concepts are completely foreign to the value system associated with compliance culture. According to one ALC leader, "The organization is not used to making data-driven decisions since money has been plentiful. But it isn't any more."

The rift between compliance culture and lean is a barrier to transformation at the ALC. One project leader highlighted the importance of culture when she described her experience: "Culture is 75% of the challenge in transformation". Another manager described how an improvement team was hampered by a few workers who were perfectly content with the status quo. They resisted changes at every opportunity. The manager added, "It's just going to take time to get those people out of the system."

Resistance to change is not exclusive to workers. Mid-level managers sometimes resist change, also. A manager of several lean improvement efforts explained that his first lean project took 18 months to implement when it only should have taken 6. The delay was caused by "managers [who] never got on board." Workers and higher-level leadership supported the initiative, but without middle-manager support progress was slow. Why would managers resist change? One leader explained that the history of initiatives at the ALC has been "the flavor of the month." Past initiatives have included Theory of Constraints, SPC, QP4, etc. The leader continued: "Managers think they can outlive initiatives if they're stubborn. I try to convince them that it's worthwhile to change. I try to get them to see the benefits of lean."

Two organizations at the ALC, the brake and wing shops, provide an example of successful cultural transformation. These organizations exhibit "pull", which is the endogenous desire to change. According to one shop employee, "We would still do lean even if it were not the flavor of the month." Consultants who ran initiatives in these shops emphasized the interesting and fun aspects of transformation. Evidence of their success came from envious workers in nearby shops who wanted their own improvement initiatives. Additional evidence came from customers - F-16 wings. Satisfaction surveys showed a significant upward trend corresponding with the lean implementations, and the improvements were strong enough to elicit compliments from an Air Force General.

3.8 Conclusions from change efforts

Change efforts at the ALC must overcome several barriers. The inherent complexity in sustainment operations makes analysis and learning difficult. Non-market forces such as inflexible labor practices constrain potential solutions. The long-term, continual support for change initiatives may be eroded by high leadership turnover. Financial policies may prohibit the reinvestment of funds saved by improvements or encourage organizations to compete for resources rather than cooperate on shared problems. Finally, cultural resistance to change has built up in parts of the ALC.

Examples of successful change at the ALC prove that some of these barriers have been overcome. But these examples represent islands of success, not necessarily transformation on the scale of the entire ALC. Furthermore, the question of whether a change was successful must be evaluated in context. If a shop has reduced flow time by 50% does that necessarily contribute to the overall objectives such as reduced costs or increased system availability? What if the increased output from the shop is absorbed by other parts of the sustainment process so that overall performance is unchanged? Answering such questions at the ALC is difficult because change initiatives seem to be managed independently without a view of the overall impacts from changes.

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4 System models as an approach to change for complex enterprises

"There is some difficulty at the [Air Logistics Centers] in moving from data to specific actions and projects. [Center personnel] need to get their arms around the ALC." Robert Connor described a recurring challenge in enterprise change at the Centers. Connor is familiar with change efforts at each of the three Centers due to his role as Executive Director of the Air Force Materiel Command, a parent organization to ALCs (Connor 2005). Leaders at the Ogden ALC echo Connor's sentiments. According to the Vice Commander at Ogden, "Moving the analysis up to higher levels of the organization seems to result in losing a grasp on quantitative performance measures."

Daunting complexity at the Center, described in sections 2.2 and 3, acts as a barrier to understanding and quantification. Indeed, change at the ALC fits Ackoff's definition of a mess, or system of problems (1974, p. 21). Making this distinction is essential because solution strategies naturally follow from the way a problem is conceptualized. If our mental model of the problem does not match reality then we risk wasting our efforts by trying to solve the wrong problem. A side effect is that we make the problem harder. King elaborates this point:

> A primary danger in mistaking a mess for a tame problem is that it becomes even more difficult to deal with the mess. The simplest of examples illustrates this point. Asking which of your teenage kids started the argument mistakes a mess for a tame problem. Trying to tame the problem by blaming one of them usually makes things worse (1993, p. 107).

4.1 Solving the right problem

A team of change agents at the ALC - "Black Belts" in Center parlance - have approached the ALC performance targets with a toolset rooted in manufacturing, which was described in section 3.1.2. Implicit in this approach is an assumption that the necessary changes can be decomposed into a series of independent process improvements. In other words, enterprise change is a tame problem that can be stated as follows: find and remove waste and variance from individual processes until the goals are met.

But changing the ALC is a problem with high dynamic and behavioral complexity. Numerous examples from sections 2.2 and 3 demonstrate dynamic complexity with feedback and unintended consequences, while behavioral complexity arises from the need to manage competing agendas and change culture at the center, not just processes. Recognizing that change is a mess results in an alternative statement of the problem: enterprise change at the ALC entails optimizing a system of interrelated processes. Changes cause feedback and tradeoffs. We should seek to understand the interactions among parts of the system, quantify the tradeoffs, and then introduce a set of changes that satisfy ALC goals while resulting in the most favorable tradeoffs.

The following section provides a framework for approaching the problem in its alternative statement, including methods for understanding interactions and quantifying tradeoffs.

4.2 Analysis methods

Tame problems and messes should not be treated in the same way, according to King. He contrasts how the two problems are treated and offers suggestions for where to focus attention:

> Problems which cannot be solved in relative isolation from one another form messes… Rather than simply breaking things down into parts and fixing components, we examine patterns of interactions among parts. We look for patterns such as vicious and virtuous circles, self-fulfilling and self-defeating prophecies, and deviation-amplifying feedback loops… Messes demand a commitment to understanding how things going on here-and-now interact with other things going on then-and-later. (1993, p. 106)

King advocates treating messes systemically, not in isolated components. Taking this view not only changes how problems are approached, it also changes how we learn from our efforts. The "commitment to understanding" described by King requires that we use information to inform our decisions while we simultaneously test our mental models for how components of the system interact. Sterman describes this learning process:

> The development of systems thinking is a double-loop learning process in which we replace a reductionist, narrow, short-run, static view of the world with a holistic, broad, long-term, dynamic view and then redesign our policies and institutions accordingly. (2000, p. 18)

The double-loop learning process is illustrated in Figure 18. Feedback from the real world is used to inform decisions and test mental models of how the world works. Forrester stresses that all decisions are based on models, usually mental models (1961). In a double-loop leaning process information is integrated on two levels: it informs decisions, and it changes our mental models. But models also influence how we interact with the environment. Consider the cartoon in

Figure 19. The pilot's mental model is influencing how he interprets what he sees in front of the airplane.

ALC leaders talked about the difficulty in turning data into decisions in section 3.2 and in the introduction of section 4. A systems thinking approach using double-loop learning has the potential to close the gap between data and action. Two methods are offered by the author for integrating information into decisions and testing mental models: statistics (more specifically, regression and correlation) and system dynamics. These methods are not among the tools used by change agents at the ALC shown in Figure 17, which is not surprising because the techniques are intended for solving different problems.

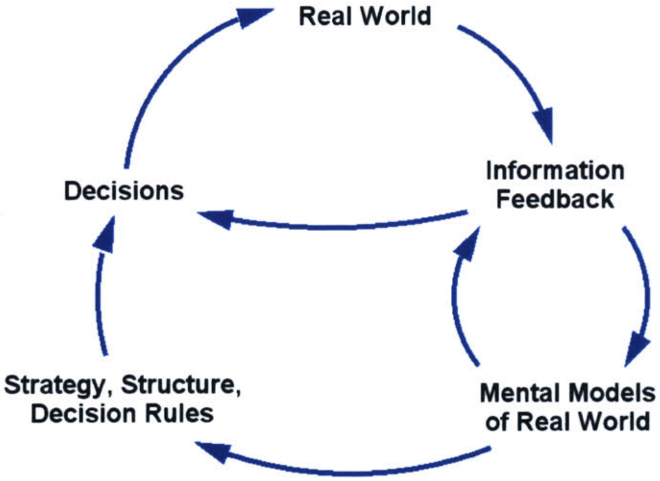

Figure 18: Double-loop learning, named by Argyris (1985) and illustrated by Sterman (2000, p. 19).

"Say... What's a mountain goat doing way up here in a cloud bank?" © Gary Larson

Figure 19: Mental models influence our perception of information and decisions.

4.2.1 Finding interactions with regression and correlation

Regression is a statistical technique for quantifying the relationship between variables and estimating future values. Regression is probabilistic, not deterministic, so the relationships between variables are subject to uncertainty. The basic framework of a multiple linear regression model is shown in Figure 20. Independent variables are related to a dependent variable with slope parameters, which are chosen in such a way that minimizes the error between data and the regression model.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \epsilon$$

y = Dependent variable
β_n = Regression slope parameter
x_n = Independent variable
ϵ = Unobserved stochasticity

Figure 20: Multiple linear regression model.

Note that the selection of dependent and independent variables is completely up to the investigator. Regression techniques make no distinction between cause and effect; it focuses on correlation. For the purposes of this thesis the dependent variable will be one of the metrics defined in the ALC goals: cost, schedule, and availability.

Oliver developed a regression model to estimate F-16 mission capability (2001). His aim was not forecasting, however. The Air Force has an accurate forecasting model called FAMMAS (Funding/Availability Multimethod Allocator for Spares), which predicts the likelihood of a spare part being available when needed. As the title suggests, the model is based on spare parts funding levels. Oliver described some limitations to the model:

> While FAMMAS is an effective tool for predicting [mission capability] rates, it does not adequately consider other significant factors besides funding. Furthermore, it does not identify potential cause-and-effect relationships that might be manipulated to affect future [mission capability] rates; it just projects trends into the future. (2001, p. 3)

Oliver's goal was to build a model that predicted F-16 mission capability with additional factors that may have a more direct, causal relationship with capability. Stepwise regression techniques were used to identify influential factors, which were selected from a set of factors shown in section 2.2.2, by selectively adding and removing factors from the model. The most influential factors included cannibalization rates, the number of aircraft awaiting maintenance work (NMCM rate), the number of aircraft in the inventory, and the quantity and experience level of aircraft technicians. Further analysis on these factors may suggest where causal relationships exist. Russel (2000) conducted such an analysis by applying causal modeling techniques in which hypothetical models are tested against less restrictive models. His analysis showed that cannibalization is strongly associated with mission capability in a way that suggests a causal relationship. Russel's causal model was based on regression and correlation analysis. Oliver and Russel used similar data sets for their analyses, but neither used data from depot operations such as the number of aircraft in the depot over time.

Correlation is similar to regression in that it quantifies the relationship between variables. The strength of the relationship is characterized by a correlation coefficient, which is a measure of the linear relationship between variables. Coefficient values range from -1 (variables move in opposition) to zero (no linear correlation) to 1 (variables move together). Independent (or unrelated) variables will have a correlation coefficient of zero.

Correlation was applied to sustainment by Keating (2002), who made an unintuitive discovery: Air Force fighter jet operation costs were negatively correlated with operational tempo. In other words, flying fighter jets more was associated with lower operational costs. A potential explanation was offered with the help of more correlation analysis. Keating also observed that transport aircraft operation costs rose with higher operational tempo, as expected. Fighter and transport tempo rates were positively correlated, also as expected. Transport aircraft tend to have less spare parts inventories than fighter aircraft. Taken together these points lead to a hypothesis: that transport aircraft consume proportionally more resources when tempos are high, which leaves less resources for fighter aircraft in a zero-sum sustainment operation. Keating elaborates:

> ...[A transport aircraft depot repair] demand surge (perhaps caused by a higher operational tempo) will run through the available spares more quickly than a proportional surge in combat aircraft [depot repair] demands. Any additional demands will cause "holes" in aircraft, called mission capability (MICAPs) failures, which receive higher priority in both depot repair and transportation functions than other demands. If demands increase in response to a forcewide operational tempo surge, the combat aircraft will experience relatively fewer MICAPs than [transport] aircraft and more of the available [depot] repair capacity will be devoted to the cargo and other support aircraft. This workload emphasis shifts because the [supply group] and the [depot group] work

> with fixed overall budgets, and so can only reallocate workload to minimize the worst effects of a demand surge (2002, p. 26).

This complex behavior provides yet another example of feedback and unintuitive dynamics in the sustainment system.

Correlation and regression are useful in the context of Air Force sustainment because they can indicate interrelationships at a macroscopic level. Further analysis at a detailed level may support or negate the indicated interrelationships. Macroscopic metrics like mission capability depend on the interactions of hundreds of processes that may confound deterministic analyses. Statistical methods offer an alternative analysis method.

4.2.2 Understanding feedback and causation with system dynamics

> Many of the problems we now face arise as unanticipated side effects of our own past actions. All too often the policies we implement to solve important problems fail, make the problem worse, or create new problems. Effective decision making and learning in a world of growing *dynamic complexity* require us to become systems thinkers - to expand the boundaries of our mental models and develop tools to understand how the structure of complex systems creates their behavior (Sterman 2000, p. vii).

Sterman offers system dynamics as a worldview and a method for approaching problems exhibiting dynamic complexity. As a worldview system dynamics emphasizes complex interactions that may form barriers to learning or cause unintended consequences. As a method system dynamics emphasizes the use of models and causal loop diagrams to describe and test mental models. The method is highly interactive and iterative. Models are easily displayed and communicated, allowing others to become involved in the modeling and learning process.

This thesis is certainly not the first application of system dynamics to Air Force sustainment. Bickel used the method to analyze purchasing and supply chain management of F-100 engines, the main engine of the F-16 and F-15 aircraft (2003). Bickel's conclusions give some indication of the potential scope of system dynamics. He recommends a dramatic reduction in the number of contracts per supplier, and an increase in supplier development efforts from the Air Force to improve process efficiency and reduce transactional costs. Policy recommendations such as these may not arise from analyses that constrain problem boundaries to single domains such as economics or engineering, or single organizations such as the Air Force or suppliers. In the system dynamics worldview problem boundaries are continually tested and expanded to include influential factors.

Basic elements of system models and causal loop diagrams are shown in Figure 21. In the upper right part of the Figure the relationship between cause and effect is indicated with an arrow. A stock and flow structure is shown on the upper right side of the Figure. Stocks can represent quantities that accumulate or dissipate over time. For example, a bathtub is a stock where the faucet regulates inflow and the drain regulates outflow. The bottom of the Figure shows reinforcing feedback - more chickens result in more eggs that result in more chickens - and balancing feedback where interactions tend to mutually cancel one another. Reinforcing loops are denoted with an R, while balancing loops use B. Plus (+) and minus (-) signs on arrows indicate whether the parameters move together or in opposition. For example, more chickens result in more eggs, so the arrow connecting chickens and eggs has a plus (+) sign. More road crossings result in fewer chickens, so this arrow has a minus (-) sign. These basic building blocks can be combined to represent complex systems and interactions.

The dynamic behavior of complex systems is often dominated by feedback loops. System dynamics is useful for identifying feedback loops and designing policies that exploit them.

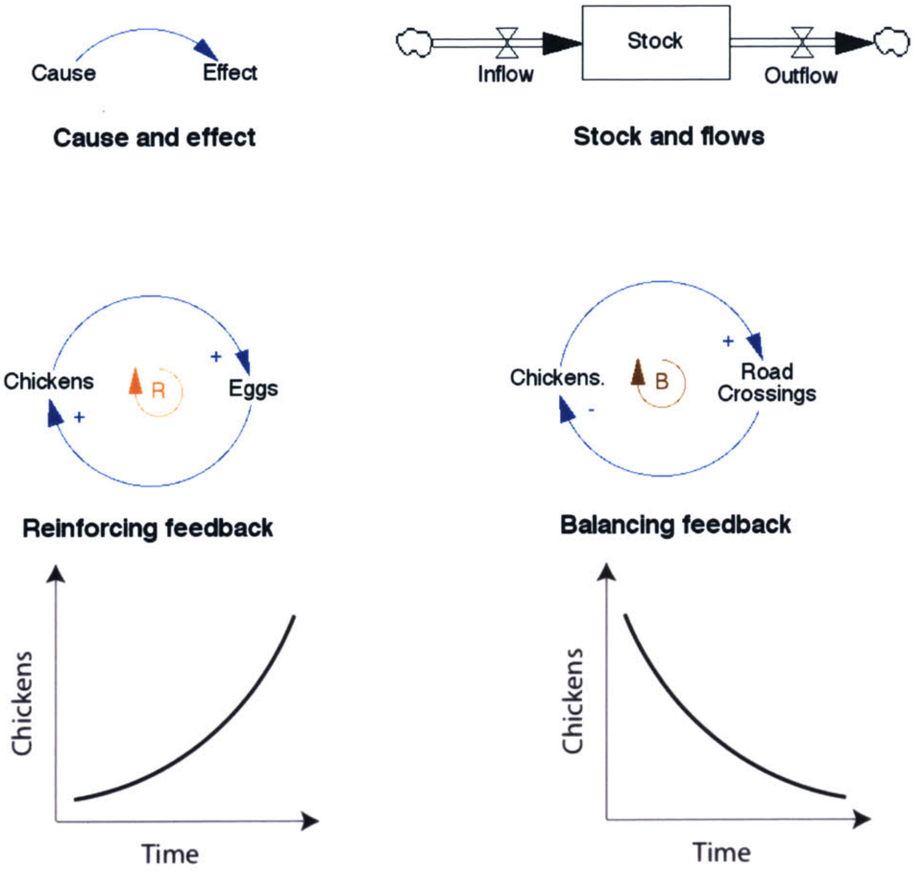

Figure 21: Elements of system dynamics models and causal loop diagrams.

4.3 Hypotheses

When regression, correlation, and system dynamics are applied to change at the ALC then what is the outcome? Three hypotheses are developed and supported with these methods, observations from the ALC, and findings from the literature.

4.3.1 Is system availability conserved?

Conservation is a term that has a special meaning in science. It is applied to measurable properties that cannot change over time. Consider the motion of a satellite around the earth, for example. The satellite's kinetic energy (speed) and potential energy (altitude) may change continuously, but the satellite's total energy, the sum of potential and kinetic energy, remains constant. The total energy is conserved.

In science conservation is not a product of coincidence but a consequence of immutable laws of physics. The question about system availability being conserved is intended to draw attention to an observation: F-16's seem to move between different categories of non-mission capability, but the overall system availability rate changes very little. Consider the data in Figure 22. For a six-month period, from November 2003 to April 2004, the system availability rate is practically constant. But the mix of F-16's is changing significantly over this same time period. For example, from February to March the number of aircraft in the depot rose by 21. However, aircraft awaiting parts (TNMCS) and maintenance (NMCM) fell by 7 and 13, respectively, leaving the total number of available aircraft almost unchanged. Before November 2003 and after April 2004 there is more significant variation. The gap between the minimum and maximum values of system availability is 2.5%.

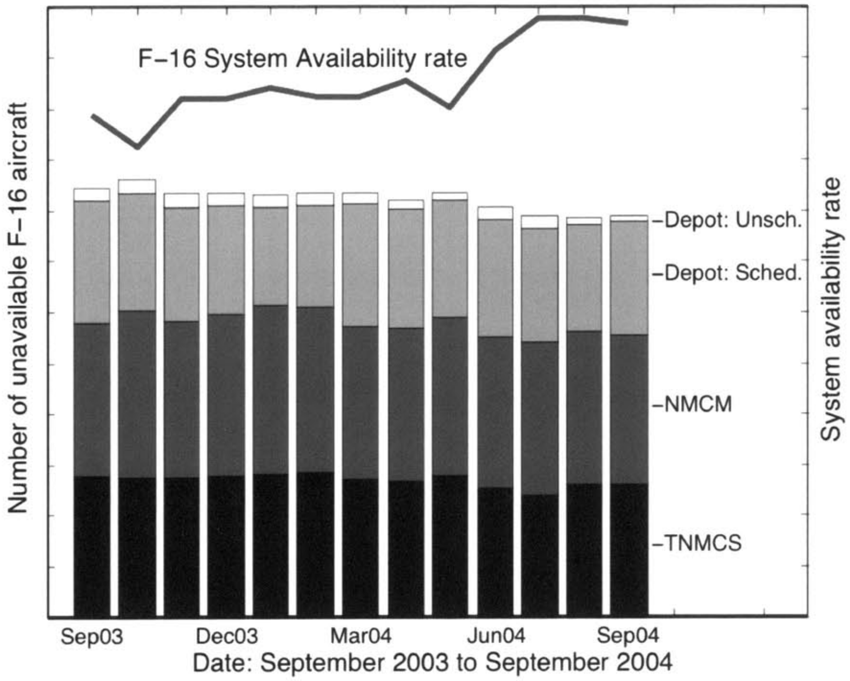

Figure 22: F-16 system availability rates and non-mission capable aircraft.

Correlation analyses using these data result in the correlation coefficients shown in Figure 23. Only two of the correlations are statistically significant at a confidence level greater than 95%: the correlation between aircraft awaiting maintenance (NMCM) and scheduled depot maintenance, and the correlation between aircraft awaiting parts (TNMCS) and aircraft awaiting maintenance (NMCM).

Category	Supply (TNMCS)	Maintenance (NMCM)	Depot - Scheduled
Maintenance (NMCM)	0.591 *		
Depot - Scheduled	-0.322	-0.630 *	
Depot - Unscheduled	0.201	0.426	-0.122

Note: * indicates that the correlation is statistically significant at a >95% confidence level.

Figure 23: Correlation between categories of unavailable F-16 aircraft, September 2003 - September 2004.

These data suggest two interactions. First, there is a negative interaction between the number of aircraft undergoing scheduled depot maintenance and the number of aircraft awaiting maintenance (NMCM). These two categories move in opposition since their correlation coefficient is negative. Second, there is a positive interaction between the number of aircraft awaiting maintenance (NMCM) and the number of aircraft awaiting parts (TNMCS). These two categories move together since their coefficient is positive. Claims regarding causation, like depot work causes lower NMCM rates, cannot be supported with these data because correlation cannot prove the existence of causation.

Taken together these two correlations show how changes in aircraft awaiting parts or maintenance tend to be absorbed by changes in aircraft undergoing depot maintenance. This behavior is consistent with an operation in which system availability is conserved. A recommendation naturally emerges from these findings: quantify and model the interactions between parts of the sustainment operations. Understanding these correlations is critical to raising the F-16 system availability rate because at least two categories of unavailable jets must be reduced in order to meet the system availability goals. The following section presents a hypothetical explanation for how this correlation arises.

4.3.2 Does local optimization result in lost performance?

Local optimization refers to improving one part of a system without regard to the overall performance of all of the parts. For example, the Defense Department acknowledges that current parts procurement policies "... are generally biased towards the purchase of low cost/high-demand items versus those critical spare parts that would most improve mission capable rates" (GAO 2003a, p15). Purchasing low cost / high-demand parts maximizes supply effectiveness, a measure of how often a part is available when needed. This is good for the supply organization because supply effectiveness is considered a key metric, but it hinders aircraft availability.

A model was developed to test whether changes to the F-16 supply and depot operations result in the expected benefits to F-16 system availability. The model, shown in Figure 30, is designed to replicate two of the correlations described in the last section. Segments of the model and the underlying assumptions are described in the following sections.

Aircraft in the depot

The number of aircraft in the depot is regulated by two rates: "Depot Induction Rate" and "Fix Rate: Depot", as shown in Figure 24. Aircraft move from the depot, into the pool of mission capable aircraft, and back into the depot over time. This loop is designed such that the number of aircraft in the depot is independent of other parameters in the model. In reality depot maintenance is scheduled by the Air Force, and it is driven by the need to upgrade or overhaul aircraft. Depot improvements that reduce flow days (the amount of time aircraft are in the depot) will increase the "Fix Rate: Depot" parameter and reduce aircraft in the depot.

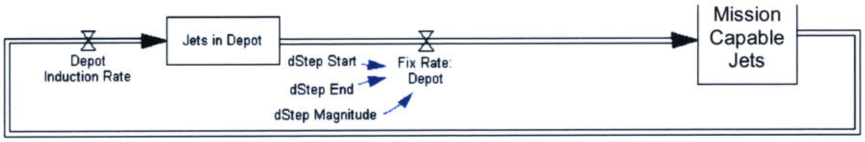

Figure 24: Jets move between the depot and the pool of mission capable jets.

Jets awaiting maintenance

The number of jets awaiting maintenance is regulated by the rate at which aircraft break, the "Break Rate: Maintenance" parameter, and the rate at which aircraft are repaired, the "Fix Rate: Maintenance" parameter, as shown in Figure 25. In the model the break rate is proportional to the number of mission capable jets; thus more jets result in more breaks. How would such behavior arise? It would naturally occur if the amount of flying hours changed with the amount of aircraft on base.

This assumption may not be realistic when the demand for flying hours is completely fulfilled. The Air Force plans flying hours with considerations such as training needs and mission needs. If all planned flying hours are achieved then extra aircraft may be unused. However, if the demand for flying hours is unmet due to a shortage of aircraft then adding more aircraft will result in increasing flying hours and break rates.

A former F-16 mechanic offered an explanation for how the break rate could be proportional to the number of aircraft available *even when all flying hour demand is met*. Mechanics regularly perform inspections and other preventative maintenance during lulls in activity so that surges in flying hours cause fewer breakdowns. Indeed, the number one cause of aircraft awaiting maintenance is inspections (USAF 2005).

Three more pieces of evidence corroborate the link between the number of mission capable jets and the NMCM break rate. Oliver's regression analysis found that the number of aircraft on base was highly correlated with mission capability rates (Oliver 2001). This finding suggests that putting more aircraft on base depletes limited resources: the supply of parts and labor. Second, the correlation analysis from 4.3.1 shows that the quantity of jets in the depot is negatively correlated with jets awaiting maintenance. If there are fewer jets in the depot then there are more at bases, and if there are more jets at bases then there is more work for maintainers and higher NMCM rates. Third, Russel's causal model established a "resource use penalty" in which increasing the rate at which jets are repaired also increases the rate at which they are used, a balancing feedback mechanism (Russell 2000, p. 121) which is duplicated in this model.

The rate at which aircraft are repaired is proportional to the gap between target NMCM aircraft and the actual number of NMCM aircraft. This formulation allows, in a simplistic manner, for the effort of workers to match demand. In reality overtime is used to increase productivity. The "B" encircled by an arrow in Figure 25 indicates a balancing feedback mechanism: the fix rate adjusts to meet demand.

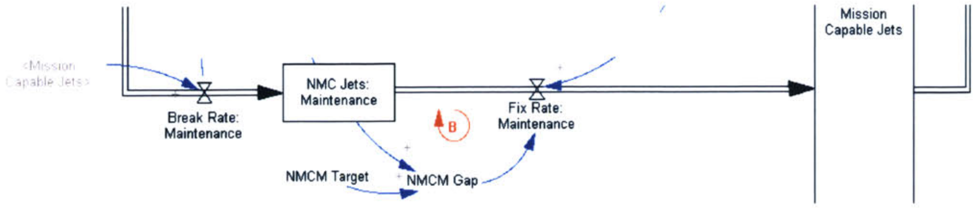

Figure 25: Jets awaiting maintenance.

Jets awaiting supply

The stock of jets awaiting supply (or parts) is regulated by two rates: "Break Rate: Supply" and "Fix Rate: Supply" as shown in Figure 26. "Break Rate: Supply" is named to follow the model's convention; the term refers to the rate at which broken aircraft become not mission capable for supply. This rate is influenced by "Supply Effectiveness", the likelihood that a part is available when needed. A value of 84% is used in the model, which agrees with findings from Wolters (2000, p. 11). Fix rates are proportional to the gap between target NMCS rates and actual NMCS rates. This formulation is consistent with Air Force practice. According to F-16 program office personnel, management attention is focused on parts problems when NMCS rates rise for a particular item - in other words, a gap has opened between expected and actual performance. The "B" encircled by an arrow indicates a balancing feedback mechanism: the fix rate adjusts to meet demand. Another parameter that influences the fix rate is the "Average Supply response time", which is 1 month in the model and 29.8 days in reality (USAF 1999). This is the average time needed for a part to go from the depot to the hands of a maintenance technician at a base.

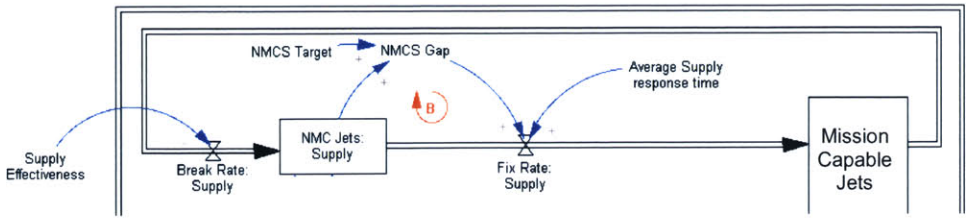

Figure 26: Jets awaiting supply.

Interactions between jets awaiting supply and maintenance

The correlation analysis from section 4.3.1 showed that the number of aircraft awaiting maintenance and awaiting parts was positively correlated. In the model, shown in Figure 27, a causal relationship exists between the rate at which aircraft await parts or maintenance. The relationship arises because broken aircraft are first placed in the NMC Maintenance category. If repairs require a part that is not available then the aircraft is declared NMC Supply. Therefore each rate is linked to the overall rate at which aircraft break.

Another interaction between jets awaiting supply and maintenance arises through the "Workload" parameter in the model. Workload represents the amount of productivity required from aircraft maintainers at bases. It is proportional to the sum of aircraft awaiting supply and maintenance. More jets result in more work.

Workload is also linked to cannibalization, the practice of removing parts from one aircraft and placing them on another. In the model the workload from aircraft awaiting supply is multiplied by a term representing extra work resulting from cannibalization. Aircraft awaiting supply cause cannibalization to grow exponentially, a relationship demonstrated by the plot in Figure 28. The exponential equation in the chart is used in the model and calibrated by a constant so that the baseline case has a cannibalization multiplier of 1.

"Workload" influences "Morale and Retention" through a third-order exponential delay with a 1-month time constant in the model (see Chapter 11 of Sterman's book (2000) for a description of delays in system dynamics models).

The arrow connecting Workload and Morale and Retention has two crossing lines, which indicates the delay. Finally, Morale and Retention is linked with "Maintainer Effectiveness", which is linked with maintenance and supply fix rates in turn.

Morale and effectiveness are difficult concepts to model quantitatively. A simplistic formulation is used in this model so that increasing workloads reduce morale and effectiveness after some delay. Has the link between workload and maintainer effectiveness been established? The title of a GAO report indicates their findings on this subject: Parts Shortages Are Impacting Operations and Maintenance Effectiveness (GAO 2001). The report states that "... one of the six factors cited by military personnel as sources of dissatisfaction and reasons to leave the military related to work circumstances such as the lack of parts and materials to successfully complete daily job requirements" (p. 2). A lack of parts leads to cannibalization, an increased workload, and dissatisfaction.

When maintenance personnel leave their replacements are typically less experienced, thus low retention drives down the experience level of maintainers. The ratio of experienced maintainers to inexperienced was highly correlated with mission capability, according to Oliver (2001). Figure 29 shows that there is strong correlation between this ratio and NMCS rates, also.

Dahlman describes how maintainer retention problems result in reduced experience and effectiveness. Note that Air Force maintainers are classified as 3, 5, or 7-level, where 3 is an inexperienced maintainer and 7 is the most experienced.

> An ever younger force such as that shown in [the figure] is less productive and requires more experienced trainers than a more mature one... A major source of this problem is the retention rate of second-term enlisted airmen... As greater numbers of these more senior 5-levels leave the service, they are replaced by junior technicians who must take on a greater share of the responsibility for maintaining and generating aircraft as well as for training 3-levels (Dahlman 2002, p. 11).

Evidence from Dahlman and the GAO shows that overworked maintainers may become dissatisfied and leave the Air Force, resulting in reduced experience and effectiveness for the maintainers who remain in the Air Force. This dynamic is marked with arrows encircling an R in Figure 27, indicating reinforcing feedback. A vicious cycle is formed where higher workloads reduce effectiveness and cause workloads to grow even more.

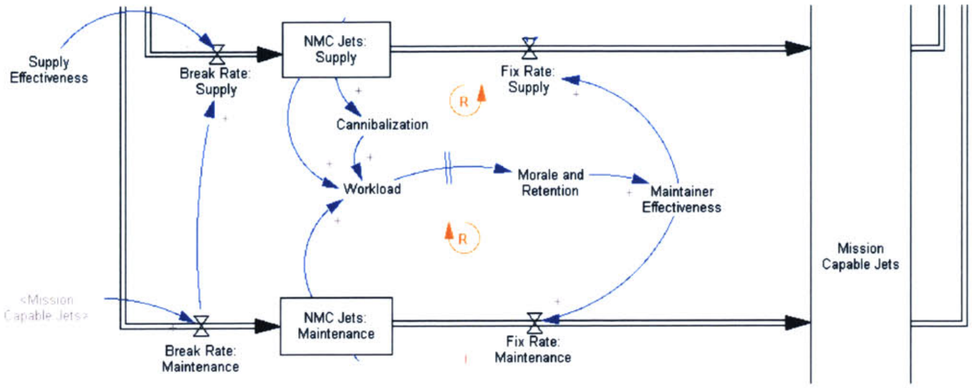

Figure 27: Interactions between jets awaiting maintenance and supply.

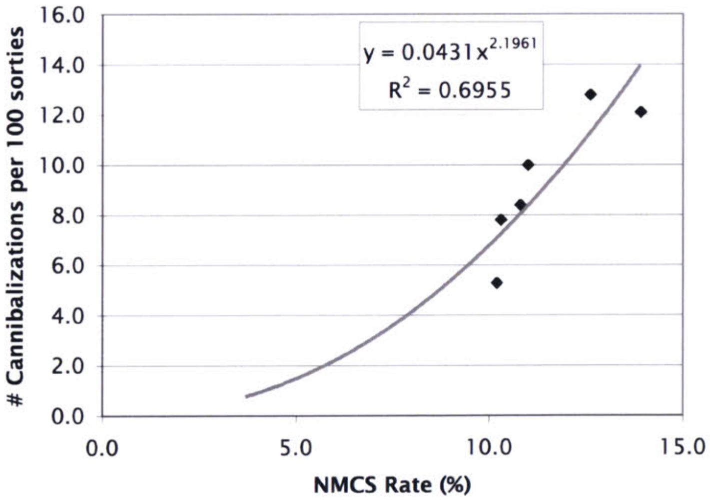

Figure 28: The relationship between F-16 cannibalization and F-16s not available due to supply shortages (NMCS). Data source: GAO (1999b, p. 7, 23).

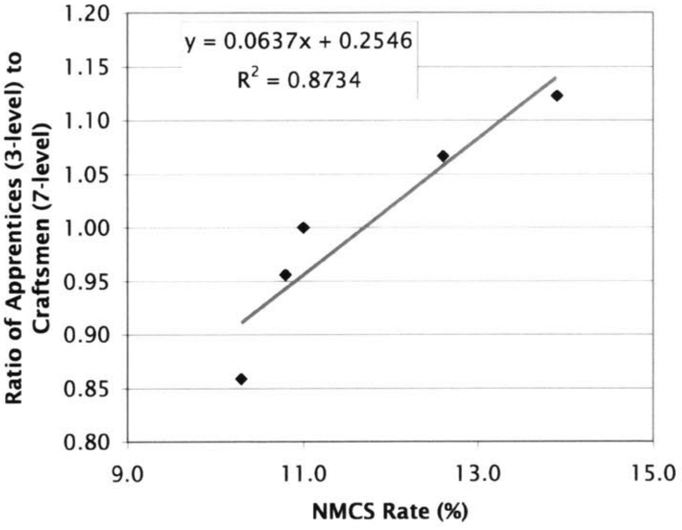

Figure 29:The ratio of apprentice Air Force maintainers (3-level) to experienced (7-level) versus the rate of aircraft awaiting parts (NMCS rate) from 1994-1998. Data source: (GAO 1999b, p. 7; Dahlman 2002, p. 9).

Limitations to the model

> *All models are wrong. Some models are useful.*
> – *Anonymous*

The complete model, built from each of the components described above, is shown in Figure 30. This model was designed with a purpose: to offer an explanation for the correlations between aircraft in the depot and aircraft awaiting parts and maintenance (see section 4.3.1).

Two types of information characterize a model. The *structure* defines how parts of the model interact, while *parameters* define the strength of the interactions. The most significant weakness of the model is the parameters defining the strength of interactions between break rates, fix rates, and other parts of the model. The parameters are simply dimensionless constants that were selected to produce the correlations shown in section 4.3.1. These constants can be thought of as highly aggregated estimates of operational parameters such as the number of broken jets divided by the number of 3-level maintenance technicians.

The preferred way to build such a model would be to use data to calculate interaction parameters. Such data was requested from the Air Force, but not provided to the author. Using correlation data to choose parameters was perhaps the next best alternative.

Since this model is dependent on the correlation analysis then it cannot corroborate it. However, the model structure is supported by independent evidence presented in this section, which does lend some credibility to the results. Furthermore, the model was reviewed by four Air Force personnel from the ALC with experience in F-16 sustainment and maintenance. They found the model formulation to be credible and results to be interesting. One suggested that the model could be used to calculate the marginal improvement in system availability resulting from changes at the ALC.

Another weakness in the model is the simplistic relationship between workload, morale and retention, and maintainer effectiveness. Evidence supports the structural connection between these parameters, but the author does not have data to calibrate the parameters individually. Indeed, such data may not exist. Dahlman developed a comparatively sophisticated model of the relationship between effectiveness and maintainer experience; Chapter 7 of his work describes his model and its limitations (2002). A more robust and complicated version of the author's model could add elements of Dahlman's model to better determine the link between experience and effectiveness.

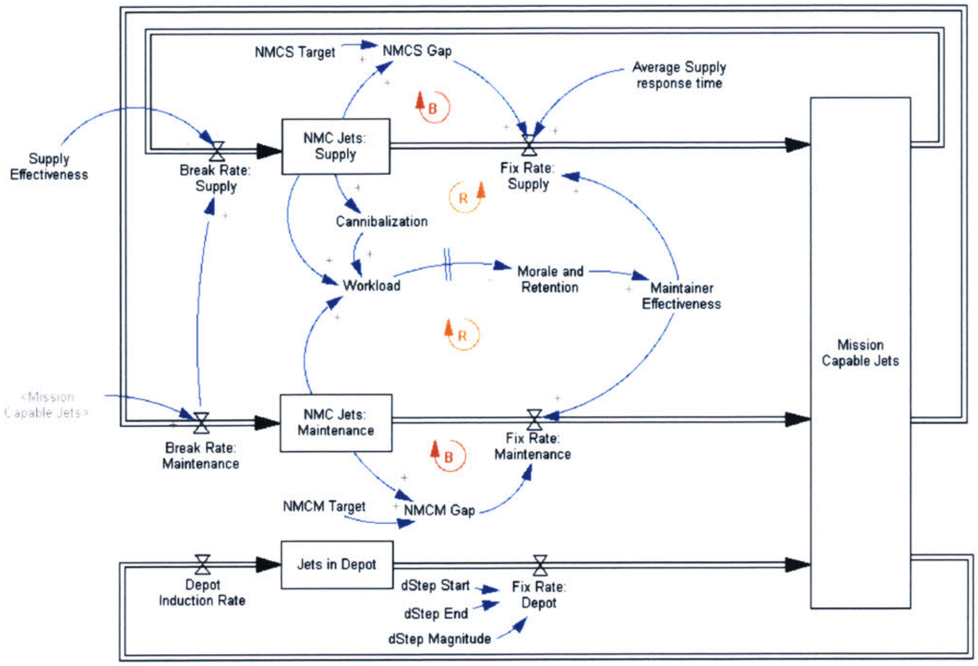

Figure 30: A system dynamics model of Air Force F-16 sustainment.

Model test cases

The model in Figure 30 is used to test a naïve hypothesis: reducing the number of depot-possessed aircraft from 10% of the fleet to 9% will result in system availability rising 1%. In other words, all of the aircraft that left the depot became available, and they are not absorbed into other categories of unavailable aircraft. This case, called "Depot improvement", results in system availability rising only 0.01% from the baseline case, much lower than the expected value of 1%. Figure 34 summarizes the results.

What happened to aircraft that left the depot? Most of them are awaiting parts or maintenance because the number of maintainers and the supply of parts were unchanged. Aircraft were shifted from the depot into the field, resulting in a 13% increase in workload for maintainers. Figure 31 shows how the aircraft were shifted while the workload increased.

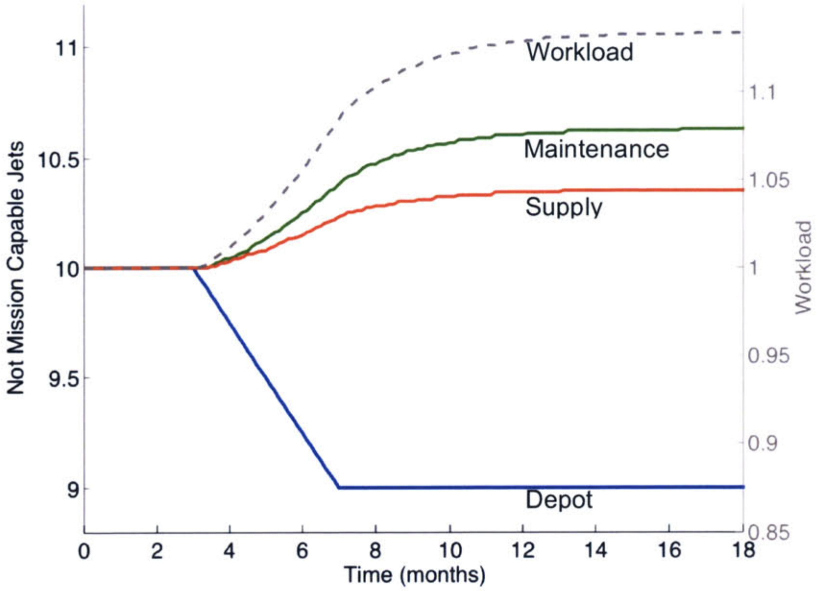

Figure 31: Depot case: not mission capable aircraft and workload.

A third case called "Supply improvement" is tested in the model. This time the supply effectiveness is increased from 84% to 86% while depot levels are left at baseline levels. The overall change in system availability is a rise from 70% to 70.19%. The workload is significantly lower than the baseline case or the depot improvement case. Cannibalization has been reduced since the number of aircraft awaiting parts has dropped, and lower cannibalization rates result in lower workloads for maintainers. However, the reduction in aircraft awaiting supply is partially offset by a rise in aircraft awaiting maintenance.

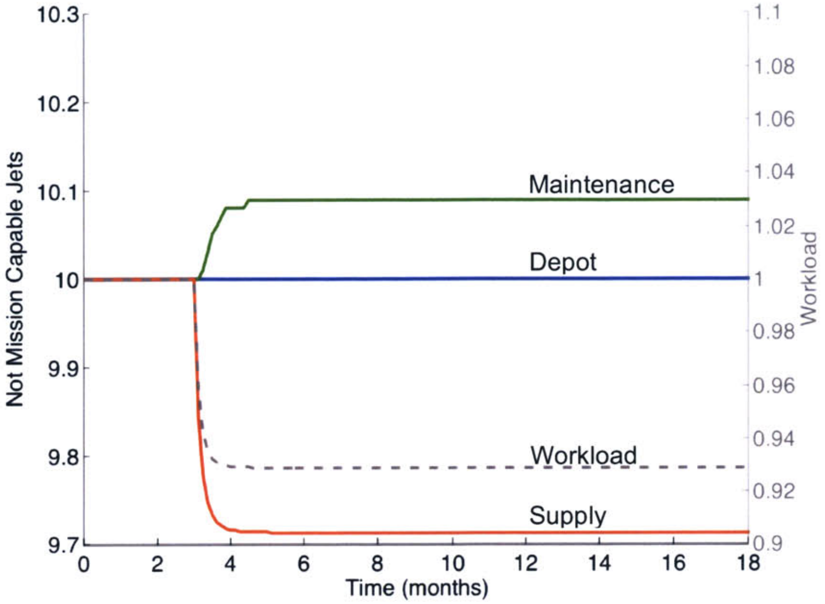

Figure 32: Supply case: not mission capable aircraft and workload.

The fourth case mixes improvements. Half of the depot improvement (depot possessed rates drop from 10% to 9.5%) and half of the supply improvement (supply effectiveness rises from 84% to 85%) are combined into one initiative. A linear model would produce the sum of the independent initiatives: system availability levels at 70.01% + 70.19% = 70.20%. The model gives a different result: system availability rose to 70.39%, while the workload dropped slightly. The distinction between this model and a linear model is an essential one: linear models cannot account for feedback. Linear regression models can give an indication of where to look for leverage, but only nonlinear models are capable of characterizing and predicting feedback.

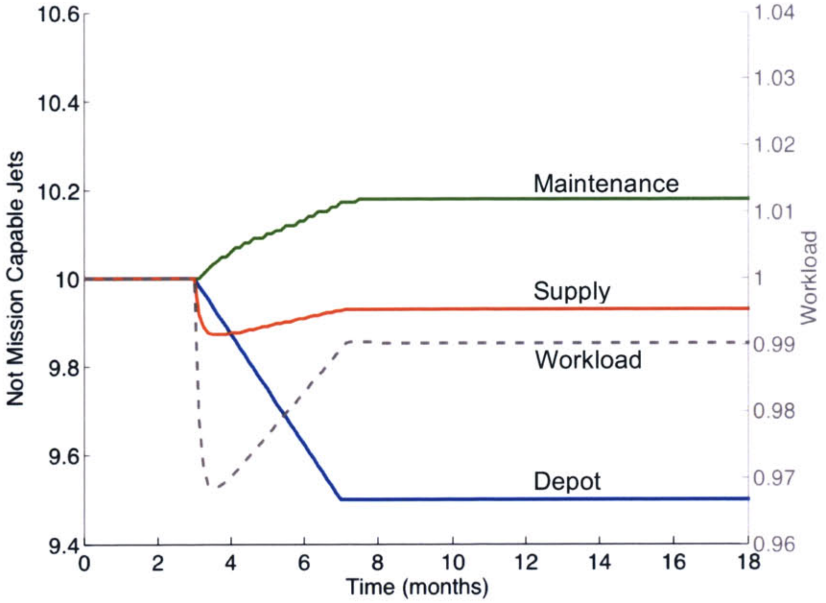

Figure 33: Half supply, half depot improvement case: not mission capable aircraft and workload.

Case	System Availability	Not mission capable Supply	 Maint	 Depot	Workload
Baseline	70.00%	10.00%	10.00%	10.00%	1.00
Depot improvement	70.01%	10.36%	10.63%	9.00%	1.13
Supply improvement	70.19%	9.71%	10.09%	10.00%	0.93
Half supply, half depot improvement	70.39%	9.93%	10.18%	9.50%	0.99

Figure 34: Results from the system dynamics model under four scenarios. Percentages are with respect to the total number of aircraft.

This model illustrates how local optimization, such as improving depot throughput without regard to the rest of the sustainment system, may not result in the intended system-level benefits. Improvements to one part of the sustainment system were largely absorbed by other parts of the system that become overtaxed by the additional output from the improvement. A balanced approach produced better results by mitigating the complications arising from increased performance.

Recommendations

Recommendations naturally emerge from a system model of operational interactions. Here, the overall goal is to avoid burnout and low morale for base-level maintenance technicians by balancing improvements in the depot with reductions in aircraft awaiting parts. Without balance there is potential to do long-term harm to the retention and experience levels of maintenance technicians. Experience is lost quickly when skilled maintainers leave the Air Force, but it is slow to build for new workers. Cannibalization rates, TNMCS rates, and reenlistment rates for maintainers should be monitored in conjunction with depot cycle time improvements.

Combining system models with cost information related to parts or improvement initiatives results in a powerful capability for leaders at the ALC: the ability to calculate the return on investment. The model can be used to calculate the sensitivity of system availability (or other parameters) to policy and performance changes. Leaders may compare the marginal rate of return for various combinations of initiatives and choose the combination that maximizes the change in system availability at a minimal cost.

A final case is used to illustrate the risk in uncoordinated improvements. Figure 35 shows the result when aircraft in the depot are reduced from 10% to 5%. In this case the final system availability is 69.11% – the improvement at the depot actually made overall availability worse. A glance at the workload shows how this occurred. Workload nearly doubled due to cannibalization, resulting in reduced maintenance effectiveness and increases in aircraft awaiting parts and maintenance.

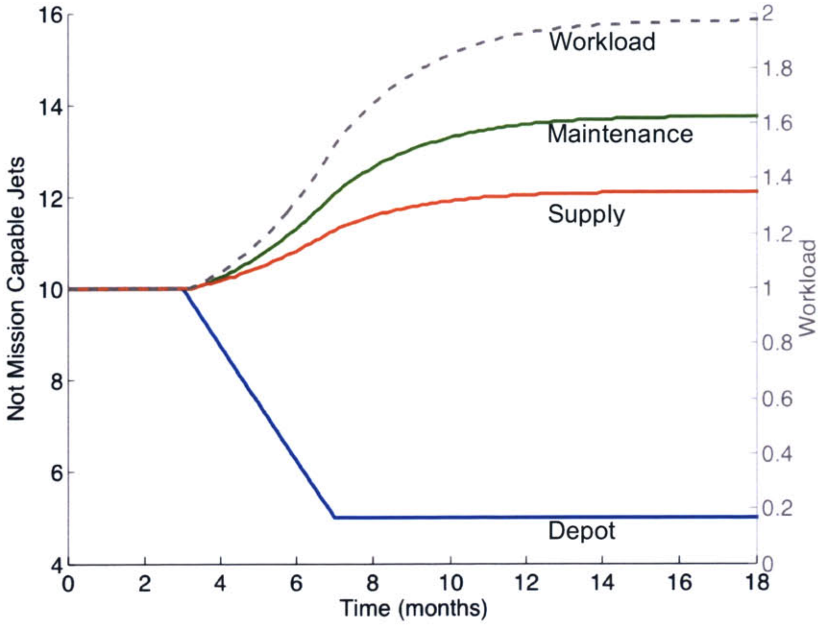

Figure 35: A second depot case: not mission capable aircraft and workload.

Recent trends in sustainment operations performance

More recent data seem to corroborate the model in terms of relationships between mission capability, aircraft awaiting parts, and aircraft awaiting maintenance. Figure 36 shows that F-16 mission capability has been steadily increasing since the middle of 2003. This increase is associated with a pronounced drop in aircraft awaiting parts (Figure 37) and a less pronounced drop in aircraft awaiting maintenance (Figure 38). In the model the relationship between capability rates and TNMCS is more direct than the relationship between capability and NMCM because of the amplifying effects of TNMCS on cannibalization and exponential increases in workload. Additional data for the number of depot-possessed aircraft would shed more light on these relationships. Depot data was requested from the Air Force but not released.

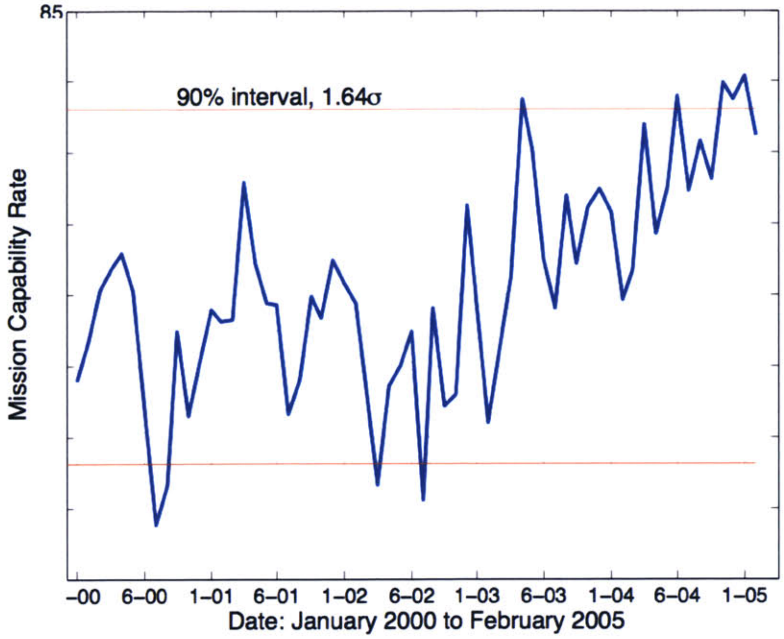

Figure 36: F-16 mission capability rates over time.

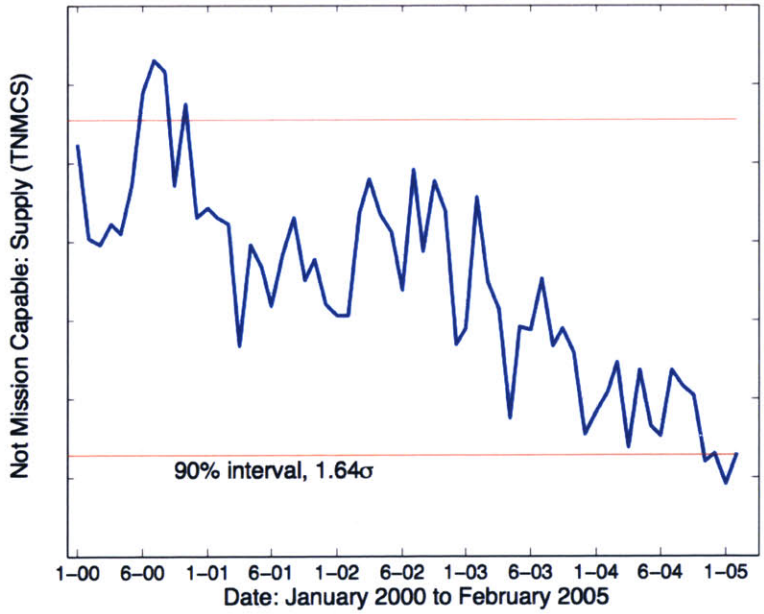

Figure 37: Rate of F-16 aircraft not mission capable due to supply shortages (TNMCS).

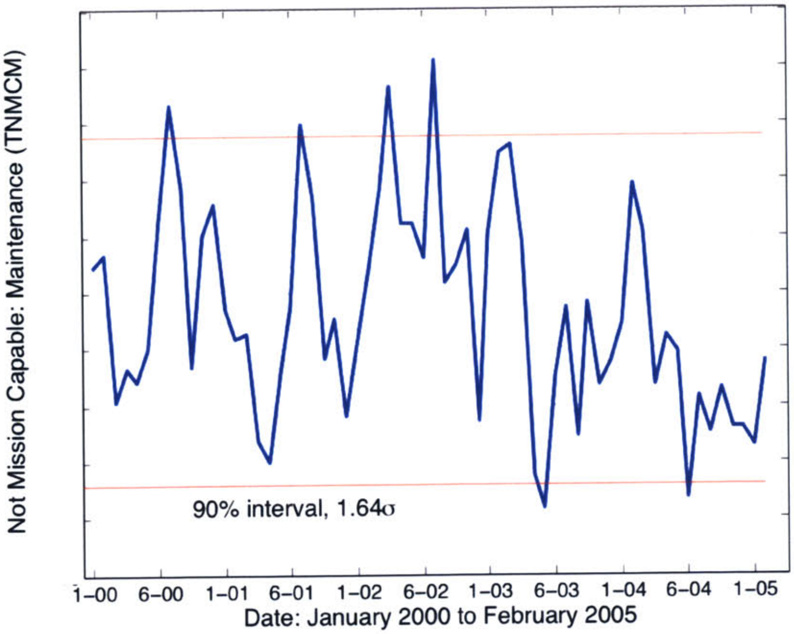

Figure 38: Rate of F-16 aircraft not mission capable due to maintenance (TNMCM).

4.3.3 How has the Ogden depot maintenance organization advanced improvement efforts?

The depot maintenance wing at the ALC is widely acknowledged as having more experience and success with lean change efforts than other parts of the ALC such as the supply organization. When asked about the disparity between the depot and other parts of the ALC the depot wing leader attributed the gap to three factors: 1) the nature of work performed within each organization, 2) more spending flexibility within the maintenance wing, and 3) the maintenance wing leadership's personal investment in lean and their willingness to take risks.

Each of these three factors fit neatly into a causal loop diagram of sustainable, self-reinforcing process improvement developed by Keating (1999) and shown in Figure 43 with minor modifications. Keating developed the diagram by analyzing improvement efforts in numerous companies. The following sections will describe each loop of the diagram.

Employee Pull

The self-reinforcing loop labeled "employee pull" shown in Figure 39 is driven by "employee perception of program value" resulting in "commitment to improvement program" and greater "improvement results". Keating (1999) found that the ability to sustain this feedback loop was a key differentiator between failed improvement efforts and successful ones.

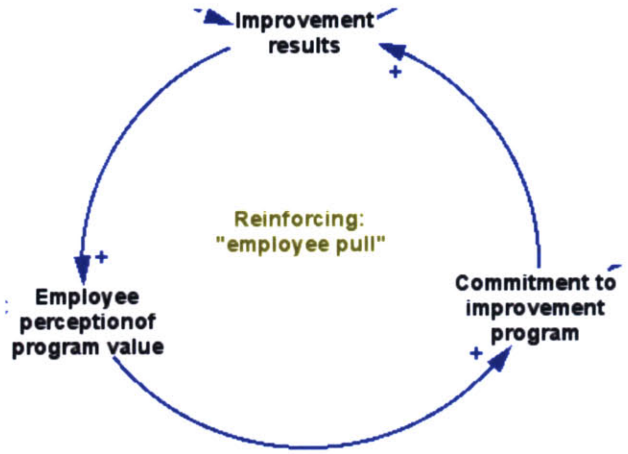

Figure 39: The "employee pull" loop.

Tougher challenges

A balancing loop called "tougher challenges" becomes stronger as easier problems are solved. Initial improvement efforts tend to be directed at simple problems. Harder problems of higher "organizational and technical complexity" are tackled over time so that the "improvement half life" increases, leading to less "improvement results".

Figure 40: The "tougher challenges" loop.

Short tenure

The "short tenure" balancing loop, shown in Figure 41, is driven by the turnover in leadership that tends to weaken leadership support for long-term process improvement initiatives. Without leadership support the employee perception of the improvement program value will be diminished. However, reinvestment in the improvement program can mitigate this loss and improve employee perceptions.

Figure 41: The "short tenure" loop.

Diffuse benefits

When the benefits of improvement programs are intangible or distant the commitment to the improvement program may suffer, according to the "diffuse benefits" balancing loop. Problems with increasing organizational and technical complexity tend to reduce tangible results.

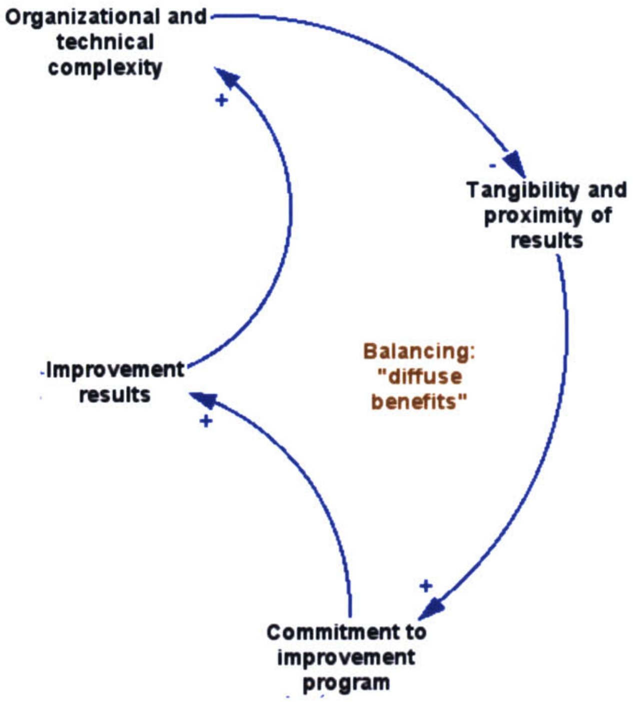

Figure 42: The "diffuse benefits" loop.

A comparison between the Depot Wing with other parts of the ALC

The complete causal loop diagram in Figure 43 shows that the depot maintenance wing has two inherent advantages over other parts of the ALC. There is greater tangibility and proximity of results, and there is greater spending flexibility that allows reinvestment in improvements. Duplicating the success of lean initiatives outside the depot maintenance organization will require efforts that overcome the balancing loops that hinder self-sustaining change.

In the depot the benefits of process improvements tend to be tangible and local. Reductions in work-in-process result in more space for shop workers. One technician said that a lean improvement effort in his shop caused other technicians in neighboring shops to become interested in lean, even "jealous". Improved working conditions and reduced inventory were easy to see. Compare this with the supply organization, where the benefits from improvements are less tangible. Improving supply effectiveness may help a technician at a base halfway around the globe, but that is difficult to appreciate from the ALC.

Greater spending flexibility in the depot maintenance wing allows for the savings from improvement efforts to be reinvested back into the improvement process. According to the diagram, reinvestment improves the employee perception of the program. Leadership support has a similar effect on employee perceptions.

The "short tenure" balancing loop reduces leadership support for improvements through leadership turnover. Indeed, turnover among military personnel at the ALCs tends to be very high. A team of twelve leaders had an annualized turnover rate of 67% over a nine-month period.

Recommendations

Several recommendations emerge naturally from the causal loop diagram. First, the logistics organizations must find a way to reinvest savings from improvements back into more improvements. Reinvestment may be feasible under current regulations, according to several Air Force personnel from the ALC. However, the logistics organizations have not yet developed the capability to do so.

Second, the logistics organization needs to increase the tangibility and proximity of results. One possible treatment comes from the Raytheon Paveway production line where workers build laser-guided bombs. Pilots who use Paveway in combat make yearly visits to the production line, and their presentations are extremely popular and motivational for the production workers. A similar effort at the ALC could involve pilots making presentations about changes at the ALC that have improved their unit's effectiveness.

A third recommendation is that the negative effects of leadership turnover - reduced support for long-term improvement initiatives - must be mitigated. Institutionalizing change methods is one way to address this problem. Leaders across the base would be expected to use the same set of improvement tools, not unlike Raytheon's company-wide implementation of Six Sigma. Raytheon has institutionalized their improvement methods and set expectations that leaders must abide.

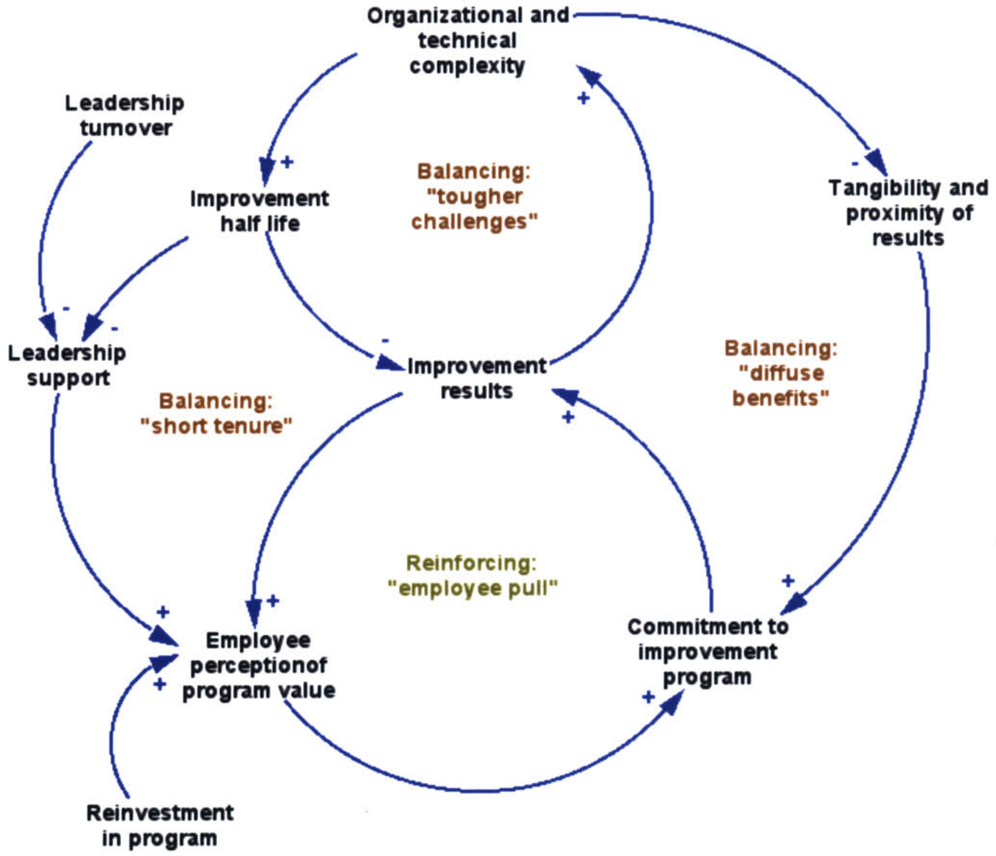

Figure 43: A causal loop diagram of improvement feedback.

4.4 Analysis method comparison

One contention advanced in this thesis is that managing change by identifying the right problem and (if it is a wicked mess) addressing it through systems methods will produce better solutions than the current methods in use. This contention will be supported by addressing three questions. Namely, when compared with the improvement management methods in use, does a systems approach...

1. ...lead to different conclusions?
2. Is it preferable?
3. How does the method influence the change process?

A number of recommendations were developed from systems modeling methods in section 4.3. In general these recommendations focus on the interactions between components of a system and how to manage them. Particular attention is given to changes that allow or sustain reinforcing, virtuous cycles of change while avoiding destructive vicious cycles. The problem scope crosses organizations at the ALC to include logistics and depot operations. Recommendations from the ALC focus on improvements that are *within* the depot or the logistics organization. This observation leads to the first question.

Do systems methods lead to different conclusions?

Conclusions from systems methods are different than conclusions resulting from methods currently in use at the ALC. Consider two examples: one system-method recommendation is to balance reductions in the depot cycle time with reductions to TNMCS rates so that cannibalization and maintainer turnover rates do not grow. Compare this recommendation with one from the ALC: identify the top supply drivers of unavailable aircraft, then implement lean initiatives in shops that produce those parts. The difference is in kind, not in degree, which should not be surprising since the two approaches arise from different worldviews on sustainment operations. Under the systems worldview the interactions between parts of the system are treated as potential leverage points for driving improvement and mitigating negative feedback. Under the ALC worldview the parts are treated individually so that top drivers of unavailable aircraft become the focus of improvement efforts.

Are systems methods preferable?

System methods are fundamentally different than the methods in use at the ALC. Therefore, assertions that one method is preferable will depend largely on the context in which the methods are applied. Addressing another question may be more illuminating: is there potential for a complementary relationship between system methods and change methods at the ALC? Evidence suggests that there is great potential for a complementary relationship in which system methods are used to coordinate and prioritize change initiatives across organizations.

Change agents at the ALC have proven their ability to improve operations at the level of a shop or depot line. But these changes are not coordinated with a system view that includes the effects of changes to other operations. System models can provide such a view to ensure that improvement efforts are not wasted or counteracted.

How do analysis methods influence the change process?

Analysis methods influence how the change process is executed at the ALC in a critical way: the method effects how the problem is defined. System methods emphasize the interactions between parts of a system and the continual testing and expansion of problem boundaries. This focus frames the problem as one of managing and exploiting interactions. Conversely, methods in use at the ALC, which are rooted in manufacturing, are designed to control and improve isolated processes. These methods emphasize a structured approach to finding the root causes of reduced performance.

A recurring message in this thesis is that sustainment operations are a complicated, highly interconnected system where searching for a single root cause may be futile. System methods are designed to analyze such problems.

Solving the right problem requires that our methods are matched to the challenges we face. Solving the wrong problem might make matters worse, and exhaust the resources for effecting change.

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5 Conclusions

Two overarching conclusions are drawn from this thesis. The first is that changing the ALC is a problem of high dynamic and behavioral complexity. Numerous examples from GAO reports, Air Force analyses, and the author's analyses demonstrate that there is a high degree of interdependence along behavioral and organizational dimensions. The second conclusion is that system models are well suited to coordinating change at the ALC because they provide insight into how a complicated system can be managed and improved.

Changing the ALC is a problem of high dynamic and behavioral complexity

Three key findings support this conclusion. First, there is significant correlation between categories of unavailable F-16 aircraft such that reductions in one category are associated with increases in another. Second, an analysis of change efforts in two parts of the ALC shows that systemic influences, such as the inability to reinvest in improvements, are hindering change initiatives in one part of the ALC. The third finding is that a model of sustainment operations suggests that independent improvement initiatives are outperformed by coordinated efforts driven with an understanding of systemic interactions.

System models are well suited to coordinating change at the ALC

Leaders throughout the sustainment community have expressed their desire to understand how sustainment operations function as a system. A hybrid approach to change is offered as a method for understanding and improving sustainment operations. System models are used to quantify and model system interactions; then policies and recommendations are drawn from the models. Recommendations may include process-level improvements utilizing change methods already in use at the ALC.

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