Final Report
September 1, 2000 - October 31, 2001

Business Process Team
Enterprise Integration Team
Sustainment Operations Team

Lean Sustainment Initiative
Center for Technology, Policy and Industrial Development
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Business Process Team

1. Research Topic

Improvement of Mission Capable Rate (MCR) depends on factors such as transportation & logistics, resource loading & scheduling, and Available Parts & materials (AP&M). As shown in Figure 1, AP&M is a function of forecasting accuracy, which in turn, depends on the software, data, and vendor reliability data. Thus, to improve MCR, it is necessary to develop a clear understanding of the process for determining parts & materials requirements. This clear understanding of how to determine right amount of AP&M also means LSI stakeholders will have better risk management, better inventory management, better contract negotiation relationship, more efficient use of human capital, smoother production management and better supply chain management.

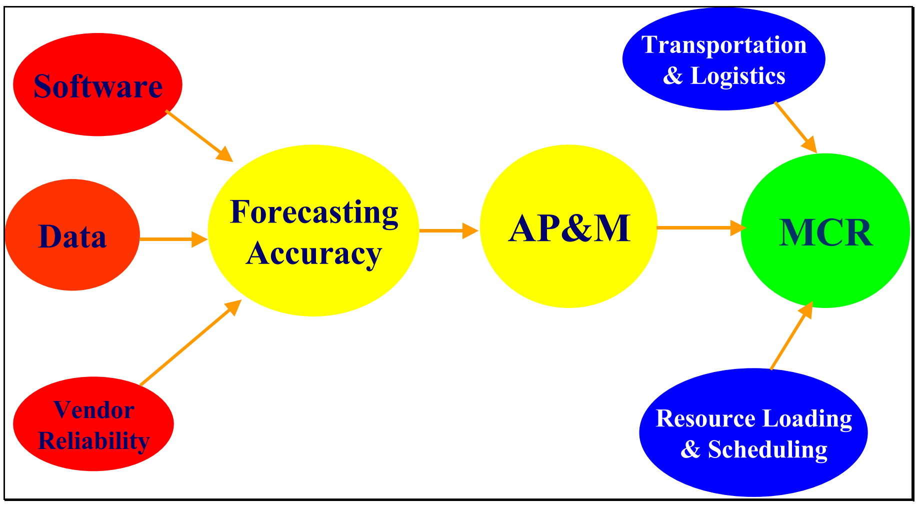

Figure 1: Relationship between MCR and key variables

2. Research Objectives

The team's objectives were as follows:

- Developed an approach to understanding how to account for parts & materials demand variability
- Developed a physical flow map for an exemplary case identified by WR-ALC: Pump & Stator

3. Research Personnel

Since the business process team is in its early stage of research, we chose to have a small number of MIT participants coupled with experienced government and industry practitioners who have deep domain knowledge about Maintenance, Repair, and Overhaul (MRO). The research personnel were as follows:

- Tom Allen, MIT
- Dan Carter, LMCO
- Wes Harris, MIT
- Alan Herner, AFMC
- Chaoyong Ma, MIT
- Alan Mathis, WR-ALC

- Carol Oakley, OC-ALC
- Jackie Staib, Honeywell
- Rich Wang, BU & MIT
- Jheri Womack, WR-ALC

4. Site Visits

1. WR-ALC, Georgia visit, October 20(?), 2000. MIT participants: Wes Harris, Tom Allen, and Chaoyong Ma.
2. Tinker AFB-ALC, Oklahoma visit, Jan. 10, 2001. MIT participants: Wes Harris, Tom Allen, and Chaoyong Ma.
3. WPAFB RIPIT Meeting, 28 February 2001. MIT participants: Wes Harris, Rich Wang, and Chaoyong Ma.
4. Tinker AFB/OC-ALC visit, May 3-4 2001. MIT participants: Tom Allen and Rich Wang
5. DLA-DSCR, Richmond VA, 22-24 May 2001. MIT participants: Rich Wang
6. Argo Tech, Lucas Aerospace, and WPAFB, 13-14 June 2001. MIT participants: Rich Wang

5. Major Findings

One of the approaches that the team used for its investigation into AP&M was the creation of data production maps for submerged fuel pump and stator. Specifically, we have attained:

- Overall understanding of the repair and replacement process for the submerged fuel pump and stator
- Functional roles and responsibilities of those involved in pump & stator inventory management.
- Physical flow of assets from flight lines to depot, and back, as shown in Figure 2.
- Inter-relationship among those responsible for pump & stator servicing (e.g., Work-in-progress)

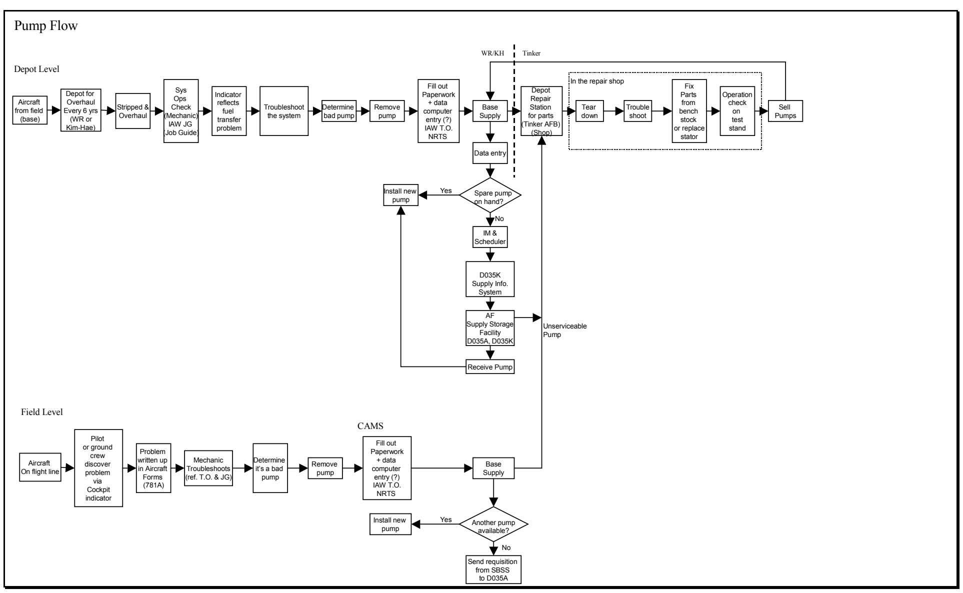

Figure 2: Physical flow of assets from flight lines to depot

6. Major Conclusions

The site visits and research findings have established a foundation for further work that will develop a clear understanding of the business processes that would improve the procurement of the right amount of AP&M. To be successful, we conclude that the following tasks to be performed:

- Develop performance metrics to improve data quality
- Track forecasting accuracy for parts needs
- Identify the impact of unavailable parts and materials
- Develop a pilot program to improve AP&M to be consistent with the actual needs

7. Major Recommendations

Consistent with the research findings and conclusions, we recommend that additional research be conducted in the following areas:

- Map Physical flows, functional responsibilities, people, roles
- Map information flows, computer systems, people
- Determine information input/output, queuing/process time, dollar/performance costs, decisions made at each point
- Collect forecast use data of historical supply and demand, etc.
- Conduct cost and Benefit analysis

Additionally, we propose a pilot program in which we would use the pump/stator case to trace and answer questions such as where in the data flow process would we introduce the changes, and what types of data will constitute the changes.

8. Major Products

Although still in the early stage of our research, two papers have been produced:

- An internal LSI working paper of 200 pages in size, which serves an a living document of supporting research evidences. This document needs to be corrected, verified, and updated as we progress. A CD of the entire documents and supporting figures have been produced and distributed to all government business process team members for clearance of security and sensitivity.
- A conference paper entitled, "Information Products for Remanufacturing: Tracing the Repair of an Aircraft Fuel-Pump," co-authored by Yang Lee, Tom Allen, and Rich Wang and published in *the 6th International Conference on Information Quality*.

Enterprise Integration Team

1. Team Charter

Define, develop and deploy integrative concepts, frameworks, practices, metrics, methods, and tools enabling the transformation of the sustainment enterprise into a more effective and efficient system providing best value to the customer.

2. Research Topic

Goals, objectives and metrics.

3. Objective

The objective of this research is to identify the most effective metrics for:

- Monitoring progress towards the achievement of system-wide goals
- Achieving changes in system-wide processes and practices, with emphasis on depot-level repair and maintenance operations, resulting in improved rates of fully-mission-capable (FMC) aircraft *and* cost reduction.

4. Motivation

Present metrics may not exhibit progress towards achieving an acceptable rate of fully-mission-capable (FMC) aircraft and reduced cost goals. MIT has created a process ("metrics thermostat") for identifying the most effective metrics used in complex industrial enterprises, which has been developed and applied for Xerox, Ford and the US Navy. The same methodology has also been recently used in a "test case" for F-16. In addition, MIT has pioneered in the application of systems thinking concepts, econometric modeling and related analytical techniques in analyses of complex systems and processes. Substantial potential benefits are expected to be derived through the use of more effective metrics. Principal beneficiaries include warfighters, as well as depot and industry MRO providers.

5. Team

- Jimmy Beeland, WR-ALC/LYPM
- Dr. Kirk Bozdogan, MIT (MIT Co-Lead)
- Lt. Ben Brandt, MIT Graduate Student Research Assistant
- Kathleen Chase, MIT Graduate Student Research Assistant
- John Crabill, AFRL/MLMP
- Prof. John Hauser, MIT
- Lawrence Hess, HQ AFMC/LG
- Jim Lengyel, OO-ALC/LGPW (Government Co-Lead)
- Nancy Long, OO-ALC/LGPW
- Nancy Thornton, OC-ALC/LGPW
- Leland Williams, Boeing Military Aerospace Support (Industry Co-Lead)
- Prof. Joseph Sussman (MIT Co-Lead)
- Dan Yoo, MIT Student

6. Focus

The team's research has focused on DMAG avionics repair and maintenance operations and processes, within the larger context of the US Air Force logistics and sustainment system. Research takes a "wide-lense" end-to-end systems perspective, from the field level to depot repair through supplier networks, including interfaces between the Defense Logistics Agency (DLA) and depot-level "organic" repair and maintenance organizations. Avionics-related sustainment costs have increasingly claimed a significant share of total component repair and maintenance costs. These costs are expected to rise sharply in the future as the problem of both aging aircraft and aging avionics systems becomes exacerbated. Meanwhile, the F-16 fleet accounts for more than half of the Air Force's total fighter aircraft inventory currently and is projected to claim over 40% of total inventory in 2015. That is, the readiness and mission-capability of the F-16 is and will remain to be critical to the Air Force's mission. Consequently, this research, focusing on metrics for managing the avionics sustainment system, is potentially expected to help improve the mission-capability rates of the F-16 fleet. Research results are also expected to bring "carry-over" benefits to other weapon system platforms as well, facing similar avionics-related sustainment challenges.

7. Methodology

The methodology employed by the team encompasses the "metrics thermostat" modeling approach for identifying the most effective metrics in complex industrial enterprises, as well as systems thinking techniques making use of causal modeling, statistical analyses, and econometric methods, combined with case studies involving site-visits and structured field interviews.

The specific research design and methodological approaches employed in connection with specific research activities are described in the individual project descriptions.

8. Activities

The team's research effort during this period has covered the following major activities:

- Completed "test case" "metrics thermostat" research focusing on the F-16 at the platform level, using monthly data on metrics and outcome variables over a number of past years for over 50 Air Force bases.

- Developed a systems understanding of the F-16 avionics sustainment operations and metrics, where cannibalization as a pervasive phenomenon is used as an overarching organizing them in addressing avionics metrics research issues:

  ⇒ Identified key processes and metrics.
  ⇒ Defined organizational interfaces (DMAG, SMAG, DLA) and examined their effects on repair and maintenance process flow as well as on performance metrics.
  ⇒ Conducted first-order causal analysis of key relationships, focusing on causes and consequences of cannibalization (e.g., impact on MRO behavioral dynamics and metrics), as part of an effort to identify metrics driving the wrong type of behavior.

- Developed a reference database on sustainment performance metrics utilized at all levels (e.g., field/base level, depot level, Department of Defense level).

- Conducted a comparative benchmarking analysis of "commercial" vs. "organic" avionics/electronics depot repair operations and metrics -- focusing on major similarities and differences in terms of goals and objectives, process flow, materials and parts management, business processes, and performance metrics -- in order to develop an improved understanding of these two sharply contrasting repair and maintenance "models", one involving extensive parts cannibalization ("organic") and the other prohibiting any cannibalization ("commercial").

- Explored the feasibility of extending the F-16 platform-level application of the "metrics thermostat" methodology to the depot level, in data requirements and availability.

9. Schedule Of Events

Major events during this period included the following:

Event	Location	Date
Participation in LSI Steering Group Meeting	Dayton, OH	6-7 Sept 00
Team activities initiation	--	11 Sept 00
Kick-off conference	--	27 Sept 00
Site-visit OO-ALC	Ogden, UT	18-20 Oct 00
Team Meeting	MIT	25-26 Oct 00
LSI Focus Team Co-Leads Meeting	MIT	12-13 Dec 00
Site-visit OO-ALC	Ogden, UT	15-18 Jan 01
Progress Briefing --LSI Steering Group Meeting	Dayton, OH	20 March 01
Participation in Site-visit HQ DLA	Ft. Belvoir, VA	22-23 May 01
Site-visit Boeing ERC	Irving, TX	16 July 01
Site-visit OO-ALC	Ogden, UT	17-19 July 01
LSI Focus Team Co-Leads Meeting	MIT	1-2 Aug 01

10. Expected Products And Benefits

This research is expected to result in Master's theses, as well as working papers, publications, web-based communications and presentations leading to the following products targeted to specific end-users (research customers, such as HQ AFMC/LG, ACC, DLA, commercial providers of repair and maintenance services) for implementation:

- New process (methodology) for identifying the most effective metrics for managing MRO operations throughout the Air Force sustainment enterprise;

- Identification and documented quantitative validation of the most effective metrics and key enabling practices at the weapon-system platform level, as well as for avionics and similar component-related MRO operations at both the field and depot levels, with emphasis on DMAG MRO operations;

- Recommendations for improving the effectiveness of metrics, with particular emphasis on avionics and other component-level sustainment metrics;

- Recommendations for improving the effectiveness of avionics and other component-related sustainment metrics, as well as related policies, procedures, processes and practices;

- Analytical framework for tradeoff analyses to identify system-level performance implications of component-level (e.g., avionics) management intervention strategies and associated metrics, linking weapon-system mission capability to sustainment of specific components;

- Metrics implementation toolset (e.g., cascading metrics framework; tradeoff decision analysis tool; metrics dependency matrix);

- Documentations of "lessons learned" and benefits for both government and commercial providers of sustainment services;

- Documentation of work products to communicate the results of the research effort to a wide audience of decision-makers in the US Air Force sustainment system, as well as to policy-makers, as appropriate;

- These expected products are expected to generate the following benefits: (a) better resource allocation tied to proper set of metrics; (b) reduced cost of unnecessary data collection; and (c) systemwide performance improvements (cost, aircraft availability) realized through the use of more effective metrics. Principal beneficiaries will include warfighters, as well as depot and industry MRO providers.

11. Plans

Project descriptions for recommended research and pilot projects for the year ahead are:

- Applying "Metrics Thermostat" to the Sustainment of the F-16 Falcon

- Avionics Metrics Framework: Cost and Value Models for Optimizing System-Level Performance

- Pilot Project on Avionics Systems Sustainment Metrics

Sustainment Operations Team

1. Research Topic

Under ideal conditions, the right types of materials and parts would be available in the right quantities, at the right place, at the right time, and at affordable cost in order for the government and industry air force sustainment system to provide the required services efficiently, flexibly, and responsively under varying demand conditions. However, materials and parts shortages have led to a number of critical systems to have an unusually long Awaiting Parts (AWP) status during normal maintenance, repair and overhaul (MRO) operations. The situation has caused high cannibalization rates and long cycle times for MRO operations for some critical systems. In a few cases, the AWP problem has been documented to be a reason for poor mission capability rates on associated weapon systems. Given this critical situation, the Sustainment Operations Team was charged with researching the underlying causes to the AWP problem and the impact that this problem was having on government and commercial MRO production operations.

2. Research Objectives

The team's objectives were as follows:

2.1 To investigate the root causes to the awaiting parts (AWP) problem and the impact that this problem was having on government and commercial MRO production operations.
2.2 To recommend possible solutions.
2.3 To develop a proposal for a pilot project to implement the recommended solutions.

3. Research Personnel

Agripino, Mario	MIT
Boden, Brench	AFRL/MLMS
Cathcart, Tim	MIT
Chase, Kathleen	MIT
Davis, Allison	MIT
Israel, Deryl	WR-ALC/LJ
Mansoori, Nuri	Boeing ROES
Mathaisel, Dennis	MIT
Patrick, Wayne	MIT
Phillips, Matthew	HQ AFMC/LGPP
Raymond, Neil (Skip)	GRCI
Rosenfield, Don	MIT
Schubert, Mary Anne	WR-ALC/LGS

4. Research Methodology

The methodology that the team used to conduct its research included:

4.1 Developing a survey instrument for the MIT researchers to use to collect information on the materials and parts problem.
4.2 Choosing two case studies, an airframe component and an avionics component, that were representative of the problem.
4.3 Conducting a High-Level Value Stream Mapping (VSM) analysis (commercial and military) on the case studies.
4.4 Identifying and investigating other commercial and military sites with similar problems.

4.5 Identifying effective/best practices from benchmarking commercial and military sites.
4.6 Conducting a literature search on possible solutions.
4.7 Using fundamental lean principles as guidelines to conduct the research.

5. Team Activities and Schedule

5.1 The team developed a survey instrument to collect information.
5.2 The team selected 2 case studies, a C-141 airframe component and an F-15 avionics component:

a. C-141 Skin Panels:
Kevlar with Aluminum honeycomb core
NSN: 1560-01-457-4500SX
Part No.: 9579749-10
Kevlar with Divinycell or AL honeycomb core
NSN: 1560-00-012-8057JH
Part No.: 3W12030-124

b. F-15 Wide Field Of View Heads Up Display, NSN 1270-01-361-9240FX
Power Supply
NSN: 6130-01-308-7643
Cable Assembly
NSN: 5995-01-290-2866

5.3 Site visits and team co-leads meetings:

a. Site visit: Boeing (Avionics - Irving TX), 2 November 2000
b. Site visit and team co-leads meeting: WR-ALC (LJP, LYP), 3 November 2000
c. Site visit: WR-ALC (LJP, LYP), 4-5 January 2001
d. Site visit: Boeing (Avionics - Irving TX), 26 February 2001
e. Site visit: Honeywell (Commercial - Irving TX), 26 February 2001
f. Site visit: Honeywell (Military - Phoenix AZ), 27 February 2001
g. Site visit: HQ DLA (Ft. Belvoir VA), 22-23 May 2001
h. Site visit: DLA Defense Supply Center Richmond (DSCR Richmond VA), 24 May 2001
i. Team co-leads meeting: WR-ALC (LJP, LYP), 26-27 June 2001
j. Team co-leads meeting: Boeing ROES (Seattle WA), 2-3 August 2001

5.4 The team collected high-level process flows at above sites, developed high-level VSMs, and investigated the AWP problem root causes.
5.5 The team conducted investigative meetings at HQ DLA (Ft. Belvoir VA) and DSCR (Richmond VA).
5.6 The team identified best sustainment practices for the M&P problem.
5.7 The team conducted a literature search on systems engineering solutions to the M&P problem.
5.8 The team drafted a Pilot Project Proposal to implement its recommendations.

Schedule of Events:

Activity	Date
Kick-off teleconference	Sep 2000
Case Study selection	Oct 2000
Team meeting @ Boeing & WR-ALC	Nov 2000
Problem Assessment Review	Dec 2000
Site visits & data collection	Jan - Jun 2001
Progress Briefing to Steering Committee	Mar 2001
Benchmarking	Apr - Sep 2001
Meetings with DLA	Jun 2001

Team Meetings @ WR-ALC, Boeing Seattle — Jul - Aug 2001
Pilot Project Proposal — Aug - Oct 2001
Final Reports — Oct 2001

6. Summary of Findings

One of the tools that the team used for its investigation into the materials and parts availability problem was a high-level Value Stream Map (VSM) of the repair process for the two case studies, an airframe component (C-141 Skin Panels) and an avionics component (F-15 Heads-Up Display). The high-level VSMs for military MRO operations were compared to commercial MRO operations. One of the team's observations was that cycle times for military MRO functions (such as testing, the actual repair process, and retesting) were favorably comparable to those in the commercial sector. In fact, lessons can be learned by the commercial sector from successes on the military side. In terms of these functions, at a high level, military MRO operations are just as efficient as commercial operations. The one exception was when there was an awaiting parts situation. For example, average time in AWP status for avionics systems was 160 hours for commercial operations[1] versus 848 hours for military operations[2].

In its investigation into the underlying reasons for these parts availability problems in the military sector, the team revealed the following:

For the C-141 Skin Panels:

a. Parts were not cataloged in the DLA system. The SPO systems engineers had revised the construction material for the panels, but it had not notified DLA Battlecreek MI for cataloging.
b. WR-ALC manufactured 14 of the parts in the last two years and had not completed the "DHA" process to record the demand.
c. No forecasts were generated for the number of panels that needed to be repaired in the future. Thus, DLA did not have a heads-up on future requirements.

For the F-15 HUD:

a. Demand increased by a factor of between 3 and 4 in the years of the team's investigation. This caused DLA's ordering process to over-react.
b. The Air Force EXPRESS system continued to induct additional HUDs, which were not necessarily needed to satisfy Mission Capable aircraft. In the end, DLA had ordered 446 power supplies to satisfy this "perceived" demand, which was greater than the actual need.
c. For the HUD power cable, the reason for the recent high demand in the cables was unknown to DLA.
d. When contract negotiations were initiated with Kaiser, the sole source supplier of the parts for the HUD, Kaiser initially was "unresponsive" to the increased demands. When Kaiser did respond, there was an "unsubstantiated" price increase of 38%, according to DLA. Kaiser stated that it has a problem getting deliveries of a component in the HUD from one of its sub-suppliers.
e. The Air Force does not own any of the data packages for the HUD cable, so it cannot manufacture the cable on its own. Thus, it must rely on the sole source supplier, Kaiser.

7. Major Conclusions and Recommendations

In assessing the above findings, the team believes the following reasons have contributed to the root causes of the parts availability problem:

[1] Source: Honeywell.
[2] Source: HQ AFMC/LGPP.

a. Existing policies/procedures (DHA Transactions, SPR Demand, Configuration Management) are not being followed.
b. Forecasting procedures are not effective. With the thousands of NSNs that must be managed, no one in the system (ALC SPOs, DLA) can efficiently look at the demand data for low-volume items to ask why the demand is changing.
c. There are no effective criteria for triage (early problem identification) on aging systems.
d. Existing policy allows some sole source contractors to be non-responsive. And, when the Air Force does not own data packages on these systems, it relies on these sole source contractors to perform.
e. DLA's safety stock algorithm penalizes low volume, mission critical, high-cost items.

These root causes reasons can be summarized into the following conclusion: **existing military policies and regulations are either not properly implemented or are no longer effective in today's environment.** Some policies violate the fundamental principles of being lean, and these adverse policies have an impact on materials and parts availability. Two examples worth noting are:

(1) Contracting practices allow a sole source supplier of key parts to be non-responsive to a call for increasing demands, so cycle time goes up and costs increase; and
(2) Configuration management policies don't provide for new technology insertion practices to be communicated to DLA, so DLA does not have a heads-up on new demands.

Given this conclusion, the Sustainment Operations Team recommends that the sustainment community consider the following ideas for improvement:

a. The parts ordering process needs closer monitoring for high cost, low volume items to ensure that the system is not overdriven.
b. Sole source contracting policies need revaluation. Implement a Diminishing Manufacturing Supply assist program for suppliers facing problems.
c. Develop a better way to do triage at the field level to capture information and problems earlier in the process.
d. Consider a policy of procuring a technical data package for problem items to allow AF/DLA to find alternate sources of supply.
e. Develop a relationship between DLA and ALC SPO systems engineers to track root causes of highly variable demand rates.
f. Consider implementing reliability-based methods to determine future parts and materials requirements.
g. Leverage the businesses process reengineering efforts that are underway in the commercial sector within the <u>Collaborative</u> Planning, Forecasting and Replacement (CPFR) program.

The team also strongly recommends that the following Proposed Pilot Project be considered for the next phase of the Lean Ssustainment Initiative.

8. Proposed Pilot Project

The sustainment system operates under a complex array of laws, regulations and procedures that are often constraining, from the point of view of lean principles, to both government and commercial providers of maintenance and repair services. Some say that the system just does not implement these laws and policies correctly. Others maintain that the acquisition/procurement process, resulting from an accumulation of countless laws and regulations over many decades, represents a pervasive, systemic, and cumbersome set of obstacles. In this environment, sustainment organizations are often impeded from adopting lean practices that would significantly reduce costs and lead times, particularly in dealing with the supplier network upon which the sustainment enterprise critically depends for the required parts and materials needed for performing repair services as well as for acquiring the needed spares and piece parts. To be truly lean, these organizations must be unencumbered from adverse regulations, and they must have the requisite incentive mechanisms for making the types of informed decisions that will help enhance their productive performance.

Therefore, two key hypotheses emerge:

> Hypothesis 1: Existing policies involving materials and parts availability are constraining the lean implementation of MRO operations.
>
> Hypothesis 2: There exist innovative management practices that could be an incentive to the adoption of lean principles dealing with materials and parts for MRO operations by both government and commercial organizations.

The LSI Sustainment Operations Team (SOT) proposes that a Pilot Project be initiated to conduct the research necessary to test and validate the above two hypotheses. Since AFMC ManTech is currently sponsoring a number of other pilot projects under the Lean Depot Repair (LDR) initiative, SOT proposes that LSI members work together in parallel with current Lean Depot Repair (LDR) efforts to identify those specific policies and practices that impact the Materials & Parts problems. Then, using its knowledge of lean principles as well as commercial and military best practices, the team proposes to identify opportunities for improvement or change to these specific adverse policies. Hopefully, through a documentation of these specific problems, backed up with solid research findings and data, a recommendation for change to these policies can be supported.

Major tasks under this project would include:

a) Identifying candidates from AF Lean Depot Repair (LDR) and the commercial sector.
b) Developing a high-level value stream map of impacting policies and practices for these candidates.
c) Identifying corresponding principles of lean.
d) Identifying those policies, regulations and procedures presenting the most serious obstacle to lean practices for materials & parts.
e) Through benchmarking, identify the opportunities for improvement or change to these adverse policies.

9. Major Team Products

9.1 Survey instrument for materials & parts researchers
9.2 Report on High-Level Value Stream Mapping
- Military
- Commercial

9.3 Two Case Study Reports (C-141 Panels, F-15 HUD)
9.4 Report on Best Sustainment Practices for Parts & Materials
9.5 Report on Automated Test Equipment Applications
9.6 Report on Systems Engineering Practices (Configuration Management)
9.7 Six Trip Reports
9.8 Pilot Project Proposal

10. References

HQ AFMC/LGPP, "Awaiting Parts (AWP)/Backorder Integrated Product Team (IPT) Study," February 2000.

U.S. General Accounting Office (GAO), "Air Force Supply: Management Actions Create Spare Parts Shortages and Operational Problems," GAO/NSIAD/AIMD-99-77, April 1999.

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