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INITIAL TOP-LEVEL CHARACTERIZATION OF THE AIR FORCE SUSTAINMENT SYSTEM

DR. KIRK BOZDOGAN
PRINCIPLE RESEARCH ASSOCIATE
CENTER FOR TECHNOLOGY, POLICY, AND INDUSTRIAL DEVELOPMENT

PROF. JOSEPH SUSSMAN
JR EAST PROFESSOR
PROFESSOR OF CIVIL AND ENVIRONMENTAL
ENGINEERING AND ENGINEERING SYSTEMS

IN COLLABORATION WITH:

PROF. THOMAS ALLEN
HOWARD W. JOHNSON PROFESSOR OF MANAGEMENT
PROFESSOR OF ENGINEERING SYSTEMS

PROF. WESLEY HARRIS
PROFESSOR AERONAUTICS AND ASTRONAUTICS

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LEAN SUSTAINMENT INITIATIVE

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Dr. Kirk Bozdogan and Prof. Joseph Sussman

In Collaboration With
Prof. Thomas Allen and Prof. Wesley Harris

Center for Technology, Policy and Industrial Development
Massachusetts Institute of Technology
Cambridge, Massachusetts

INTRODUCTION

This draft white paper presents an initial top-level characterization of the Air Force sustainment system. The first part of the paper gives an overview of the proposed conceptual framework for system characterization. The second part presents an initial top-level characterization of the system, by using this framework, and offers some preliminary suggestions or recommendations. Finally, next steps in the research process are outlined, placing the paper in the larger context of the task on system characterization and transformation.

Briefly, the objective of the System Characterization and Transformation Task is to perform a systematic analysis of key Air Force logistics and sustainment operations, functions and structures enabling system transformation toward the development of a lean and agile combat support system in the early twenty-first century. Thus, while initially the main thrust of the task is to develop an improved understanding of the entire system through systematic analysis, over the longer-run it is designed to provide an integrative framework for the full spectrum of research activities within the Lean Sustainment Initiative, as well as related research at MIT, aimed at helping to achieve more effective system integration and system performance optimization. An important point to add in this connection is that research can only identify, define, and support the implementation of the type of systemic change that is needed. Research, by itself, cannot optimize the performance of the sustainment system. The task of implementation falls into the capable hands of the sustainment community, which this research seeks to support.

Initially sponsored by the Materials and Manufacturing Technology Division of U.S. Air Force Research Laboratory (AFRL), the Lean Sustainment Initiative is a joint AFRL, Air Force Materiel Command (HQ AFMC/LG) and MIT effort. The goal of the program is to help design and implement, in partnership with other government agencies and industry, a world-class efficient, responsive and agile combat support system for the Air Force for the early twenty-first century by bringing to the Air Force sustainment stakeholder community the benefits of MIT's cumulative research experience and capabilities in the area of lean principles, practices and change strategies.

Commercial industry has realized significant benefits by employing lean concepts in large volume as well as in low volume production, logistics, and sustainment environments. Lean concepts, representing a fundamentally new framework for thinking about and managing commercial as well as public-sector enterprises, have been developed through earlier MIT-based research, including the International Motor Vehicle Program (IMVP), the Lean Aerospace Initiative (LAI), and other MIT lean-related programs. Lean principles, metrics and lessons learned through the Lean Aerospace Initiative have formed the initial research foundation for the Lean Sustainment Initiative. The Lean Sustainment Initiative leverages these and other research activities at MIT to provide the Air Force sustainment community with maximum benefits.

PROPOSED CONCEPTUAL FRAMEWORK

The challenge of *characterizing* the Air Force sustainment system is different from *describing* it, although an accurate description of the system initially is certainly a necessary first step towards characterizing it. That is, the challenge is to explain the system's behavior rather than merely to describe it. We make this distinction in order to underscore the importance of developing a deeper insight into the causes and consequences of the system's dynamic behavior, so that we can define effective management strategies and methods for achieving significant improvements in overall system performance.

We will start by outlining a proposed conceptual framework for system characterization. This will serve as a sufficiently broad and robust guide for systematic analysis. As research proceeds, this initial conceptual apparatus may well be modified and even perhaps discarded, as the central hypotheses associated with it, after being tested, are either maintained or rejected.

As a first approximation, we will employ the concepts and methods of systems science in approaching this task, drawing upon many decades of research on systems thinking at MIT and elsewhere dealing with the behavior and management of complex systems. This is also congruent with lean principles and practices pioneered through MIT-based research, which represents a systems approach to the management of complex modern enterprises.

We will argue that the Air Force sustainment system represents an excellent example of complex large-scale integrated open systems (CLIOS). CLIOS encompass many types of complex systems, such as modern extended enterprises with globalized markets, operations and supplier networks. We will give here only a high-level, abbreviated, definition of CLIOS, to get the task underway. A more extended discussion can be evolved later, as appropriate.

In adopting the conceptual framework offered by CLIOS, we ask some fundamental questions. What are the central characteristics of complex systems? What is their purpose? What functions do they perform? How are they organized to perform these functions? How do they behave, change and adapt to shifts in their environment? We also ask basic questions to identify both necessary and sufficient conditions for the survival and success of complex systems. We ask these deceptively simple questions not in the abstract but with the deliberate purpose of framing a conceptual roadmap for sustainment system characterization and transformation. We expect to use the answers to these questions as guidelines in framing most likely high-level success factors that can offer useful "lessons learned" for the sustainment community. In this way, we hope to integrate a number of current tasks (e.g., system characterization and transformation; goals, objectives and metrics; best practices) as well as additional tasks later that would offer further insights into both "what" and "how-to" types of questions in transforming the sustainment system.

A system is **complex** when it consists of a large number of interrelated components (subsystems). In addition to their high degree of complexity, such systems generally exhibit a set of other "classic characteristics." They generally are **large-scale** systems, in that they have a *large footprint* within the general environmental setting in which they are embedded. They have impacts that are *large* in magnitude. These impacts are typically *long-lived* as well as *large* in scope. Also, CLIOS are often highly **integrated**, in that the various subsystems or components within it are closely coupled through *feedback loops*. A feedback loop can be defined as the influence of a given element on other elements, where the series of relationships through which this influence stream is transmitted results in an impact upon the very element that is the source of the initial influence. Because of these closely-coupled feedback loops, the overall system behavior may be rather difficult to predict even if subsystem behavior is fairly predictable. Further, CLIOS are **open** systems in the sense that, for example, they explicitly include external social, political, economic, governmental and institutional factors. In open systems of the sustainment type, these external influences at the national or local level could have profound effects upon the system's performance. Even if the system's performance is internally optimized, these external influences could introduce considerable uncertainty and instability, requiring the use of scarce resources to attenuate and manage their untoward effects on system performance. For one thing, this makes it more difficult to define with great certainty the system's boundaries. In contrast, in closed systems there is no interaction between the system itself and its external environment, so that its boundary is clearcut and can be determined with certainty. In analyzing a complex system, a mistake often made is to treat it as *closed*, concentrating on its internal dynamics in a steady-state setting, when in fact it is *open* and its interactions with its larger environment is of the utmost importance in developing a cogent understanding of that system.

Below these top-level defining characteristics of CLIOS, we would like to draw attention to their three central features. Namely, they are typically ***stochastic,*** highly ***interdependent*** and ***dynamic.*** From these critical properties of CLIOS, we will identify key success factors for their survival and success.

First, CLIOS are typically highly ***stochastic.*** This means that they demonstrate a high degree of variability in their behavior, governed by probabilistic, rather than deterministic, events and processes. As noted below, this represents a concept of great importance in characterizing the sustainment system, which is driven by a highly variable demand pattern for repair services and the behavior of the repair system itself is governed by stochastic processes.

The nature of change in stochastic systems is rather different when compared with deterministic systems, in that outcomes are highly probabilistic and maybe even indeterminate. This is illustrated by the likely behavior of the sustainment system under up-tempo or wartime conditions, compared with the peacetime operational environment. The issue here goes to the heart of the assumptions driving wartime spare requirements estimates. Past research has shown that peacetime variability in demand levels for aircraft spare parts far exceed the variability assumptions underlying estimates of wartime spares requirements.

Second, CLIOS are typically highly ***interdependent,*** in terms of direct and indirect functional relationships, information flows, and utilization of resources. Patterns of interdependence may take several forms, depending on the nature of the feedback loops within the system. One is *degree of coupling*, which refers to the time dimension of systemwide interdependence, measuring how quickly or slowly perturbations spread among the system components. A related concept is *the degree of nonlinearity*, which pertains to how well the direction and magnitude of impacts, whatever their source, on system-wide outcomes can be predicted with a high level of confidence. A third concept is the *degree of integration*, which captures the relative magnitude of impacts originating in particular subsystems on other subsystems as well as on overall system performance.

An extension of this latter concept is the degree of *modularity vs. integrability* in a system's functional architecture, which is critical to the system's decomposability into its lower-level subsystems or components. For example, outsourcing or privatization of "organic" depot functions to commercial contractors, such as in the form of "virtual prime vendors," may well have to consider whether these functions are *modular,* displaying zero or minimal co-dependency interactions with the rest of the sustainment system (e.g., in terms of information inputs, resource needs, etc.) as one element in the decision process. A fourth concept is the degree of *centralization vs. decentralization* in a system's organizational architecture, which can also be viewed by focusing on whether its decision-making structure is *hierarchical* or *horizontal* (i.e., the extent to which information and decisions are distributed or they flow up or down a multilayered chain-of-command organizational structure according to well-established rules and procedures).

Third, CLIOS are typically ***dynamic,*** rather than static, in their behavior, in the sense that they are subject to continuous change and adaptation. A key challenge is to identify major sources and consequences of the dynamics of change. At an elementary level, for example, influence diagrams may be used to trace major variables, relationships, and directions of change. At a more sophisticated level, mathematical models, for example employing differential equations, may be created to develop a more formal, structured, understanding of the dynamics of complex systems.

In view of these key system characteristics, what are the essential conditions for the survival and success of complex systems? To contain the discussion to a reasonably simple yet robust set of generalizations, we will concentrate on three major success factors: first, in general, they must be ***sustainable;*** second, they must exhibit a capability for continuous ***self-learning (self-organization)***; and, third, they must demonstrate what we shall call flexible ***responsiveness.*** As it will be seen, these concepts, through a process of "what" and "how-to" type of drilling-down process, can offer useful insights into future actions by the sustainment community.

CLIOS must be ***sustainable,*** in the sense that they are able to adapt and continue to function under varying internal or external conditions. This raises the larger question of the necessary and sufficient conditions for the continued survival and success of complex systems, such as the Air Force sustainment system. Thus, in the sense of "lessons learned" from the behavior of successful systems, it can be said that being *adaptive* means having the capability to adjust to a shift in system purpose or objective. For example, during the Cold-War decades, primary emphasis in logistics and maintenance was placed on a "push" system characterized by large quantities of "just-in-case" inventories and long inventory pipelines in support of prolonged nationwide mobilization efforts involving large-scale theater conflicts spanning continents. This has changed radically in recent years, as exemplified by a loosely linked set of initiatives, such as Lean Logistics, aimed at improving depot repair efficiency and responsiveness where a major enabler has been the substitution of fast transportation for the traditional practice of maintaining costly inventory scattered throughout the long and slow logistics supply line. Recent changes in public-private workload allocations, as well as the emergence of public-private partnerships, reflect the sustainment system's broader adaptive behavior to meet the challenges of a post-Cold-War national security environment.

Another dimension of sustainability is that these systems must be *robust*, able to operate under a broad range of exogenous conditions. They must also be *stable*, in the sense of being able to return to an equilibrium condition when displaced from that condition because of internal or external changes. In addition, they must exhibit *continuous functionality* at certain acceptable levels of performance even after the performance of specific subsystems may have been degraded. At the same time, they must possess *back-up* or *reserve* capabilities, to ensure that the failure of one or several subsystems does not lead to system failure. Furthermore, these systems need to be both *expandable* and *scalable*; that is, they must be able to adopt and follow a well-defined growth path (*expandable*) and, in addition, they must be capable of being expanded or rationalized while retaining their fundamental form and structure. Underlying all of these basic conditions for "success" is the fundamental need of these systems, particularly in the case of "purposive" systems involving human activities, is to create more energy (e.g., "value," revenues, etc.) than the energy they expend (e.g., total cost of production). By this definition, under highly constrained budgets, it can be argued that the Air Force sustainment system is not sustainable in a fundamental sense. This point will be amplified later by reference to how the sustainment system is at present clearly stressed.

In this context, an important concept is that of *entropy,* which refers to the tendency of systems to move closer towards greater disorder and hence, instability. Entropy represents a "force" working against a system's dynamic equilibrium within its wider environment hastening its instability and, ultimately, its demise. This concept can be forcefully brought closer-to-home in the context of the Air Force sustainment system, which is undergoing systemic change. It is not far fetched to suggest that the combination of a high degree of variability in demand *and* the high degree of interdependence across a highly complex organizational structure poses considerable challenges for the sustainment system in terms of maximizing flexibility and responsiveness while minimizing total costs, including particularly what we hypothesize to be enormous transaction costs (i.e., its internal and external coordination costs). We concentrate on this important point below. An important lesson is that complex systems will tend to deteriorate into disorder and collapse unless entropy is held back through self-learning (self-organization).

CLIOS must further exhibit ***self-learning*** behavior (or organizational learning in the context of the sustainment system), which makes self-organization, adaptation, regulation and control possible. All learning, including self-learning, depends on feedback; in sociotechnical systems, learning is a goal-seeking feedback process where new information received from the environment alters the understanding of that environment and shapes the response to it. An implication of self-learning is that piecemeal adaptation to a changing environment is not likely to ensure sustainability. This is akin to the adoption of piecemeal thinking in sociotechnical systems which seeks only localized solutions and neglects to take a holistic view of the system as a whole, thus undermining any chance of improving system performance.

Finally, CLIOS must demonstrate flexible ***responsiveness*** to both internal and external changes in a number of respects. At a fundamental level, they must be able to fashion effective response mechanisms to cope with external shifts in needs and requirements placed upon the system, such as an up-tempo, national mobilization, or simply shifting priorities of external users of the system's products and services. For example, perhaps as part of a larger adaptive strategy, this may include the ability of the sustainment system to adapt to a post-Cold-War environment of combat support to the warfighters through the adoption of a variety of mutually-positively-reinforcing workshare, organizational and institutional arrangements, including public-private partnerships. At another level, CLIOS must be *flexible* in fashioning quick responses to external shifts, such as in terms of their ability to expand (reduce) existing productive capacity, redeploy existing assets quickly or, more broadly, in terms of their ability to foster continuous incremental improvements, knowledge-acquisition, and learning.

Given the proposed conceptual framework just outlined, two possible analytical paths can be taken at the outset for an initial top-level system characterization. The first is taking what might be called a **reductionist** approach, where the system can be characterized by focusing on a few of its essential features. This would allow us to make some inferences about the system's overall state along the lines discussed above, by mapping these generic system characteristics to the particular characteristics of the Air Force sustainment system. This is expected to yield insights into the overall behavioral dynamics of the sustainment system. Coupled with a deeper analysis of the system's functional and organizational architecture, this would help provide an integrated conceptual roadmap for defining strategic management interventions (e.g., through adoption of best practices) for improving the system's overall performance. Another benefit would be to define an integrated set of metrics linking system behavior to specific classes of management strategies and practices.

The second analytical path can be described as a **holistic** approach. Here, the research strategy is more inductive than deductive. Emphasis is on developing an overall understanding of the interactions within the system from which to synthesize its emergent behavioral characteristics, without necessarily first having posited "top-down" system characteristics around which to organize the empirical research process. In effect, this represents an inductive process which is initially empirical rather than theoretical but which could form the foundation for developing a more conceptual understanding of the system.

Without debating the advantages and disadvantages of either approach, it can be suggested at this point that the research process itself should pursue a feedback process of learning about the sustainment system. This can arguably be best achieved by first developing the type of conceptual framework outlined above and then testing it out by examining the sustainment system, by following a process where the initial conceptual strategy is continuously challenged and modified through well-focused research.

INITIAL TOP-LEVEL SYSTEM CHARACTERIZATION: PRELIMINARY OBSERVATIONS AND SUGGESTIONS

Using the conceptual framework just outlined, we will offer at this early stage preliminary observations pertaining to system characterization by focusing on three salient characteristics of the Air Force sustainment system: its ***stochastic*** character (i.e., high degree of variability under which it operates), its high degree of ***interdependence***, and its ***dynamic*** characteristics. The discussion is deliberately presented in this order to invite serious attention to the system's longer-term future and the dynamics of change sustaining it. Once we have developed a sufficiently clear understanding of these pivotal system attributes, we can begin to gain some insights into the system's daunting complexity and how best to manage it over the longer-run. From the early insights gained thus far, we hope to extract some interim suggestions or recommendations. We expect to build on this initial knowledge base through an iterative, progressively deepening, research process, as outlined later (below).

The preliminary observations and findings summarized in this paper are based on our cumulative research to date, including extensive site-visits to AFMC/HQ, ALCs, MAJCOMS (e.g., AMC, ACC), and DLA, as well as graduate student thesis research conducted under the auspices of the Lean Sustainment Initiative. As a result, we have assembled a considerable amount of data on the sustainment system. This is yet far from being complete, but it represents a sufficiently robust database supporting the early results presented below. It should also be noted that the discussion presented here touches only on some of the major points, leaving out a lot of details that can be incorporated later.

Stochastic System Behavior

A good place to start is the high degree of variability in demand for repair services facing the sustainment system. This creates a compelling case for the need to pursue a flexible and ultra-fast-responsive operational, organizational, and management strategy. The premium is placed on responsive organizational structures, functional operations, processes, and business practices.

The source of the high degree of variability in demand is the dramatic variances in removal rates of complex high-technology components. This makes the calculation of spares requirements extremely difficult. This problem is well recognized by the Air Force, which has invested considerable resources into the development of mathematical models for analyzing and forecasting demand requirements. Frequently, a Poisson process is used to depict removal processes or, looking at it another way, to forecast spares requirements. In inventory theory, demand follows a Poisson arrival process, which has a variance-to-mean ratio (VTMR) of 1. The further the VTMR is from 1 the poorer is the fit between the mathematical model represented by the Poisson process and the actual removal rates. Often, VTMR well exceeds 1. The practical implication of this is that if the system buys or repairs components assuming a VTMR of 1, it would face shortfalls during periods of high demand, depending on the resupply response behavior of the repair system. In cases where the VTMR falls blow 1, the system would tend to overbuy (oversupply) stocks for these items. In other words, actual demands may prove much more erratic than assumed by the Poisson process. For this reason, a negative binomial distribution model, which assumes greater variance than does the Poisson model, is seen more descriptive of the Air Force removal processes.

In more technical terms, while the Poisson model posits a single-parameter probability distribution whose variance always equals its mean, the negative binomial distribution model has a variance greater than its mean and provides a two-parameter family of probability distributions which allow the approximation of a wide range of distributions (through an estimation of their means and variances). The behavior of the resupply pipeline, as well, is modeled through similar approaches. In the final analysis, however, how well these approaches actually capture the real-life processes remains an open question. Moreover, the VTMRs are likely to be higher under wartime conditions. They are also likely to be higher for high-activity weapon systems compared with low-activity weapon systems. To make matters worse, enemy attacks on critical test equipment, personnel or spares at forward operating bases would only exacerbate the variances in demand rates and, in fact, create many sources of uncertainty facing the sustainment system.

Other sources of variability, as well, pose difficult challenges. For example, in a pervasive environment of aging weapons systems, once a component is inducted into the repair process at a depot, it may be discovered after its disassembly and inspection, that the repair of the component may require different types of parts and supplies which could not be predicted beforehand. For instance, the component may require specific customized parts that are now out-of-production or they may exhibit diminishing sources of manufacturing. That is, the variance in lead times associated with obtaining the necessary parts and supplies required by the repair process introduces another, very important, source of variability and uncertainty. Considerable variability also directly affects shopfloor activities and processes. Two identical landing gears from the same type of aircraft inducted into the repair process may end up following quite different flow paths through the shop, depending on the condition of the individual subassemblies or units following disassembly and inspection. Many additional examples of sources of variability or uncertainty can be given, each essentially compounding the others. The net result is a highly stochastic process requiring response strategies with a premium on flexibility, agility and resourcefulness. It is for this reason that the existing organizational structure of the sustainment system, as well as established policies and practices, need to be examined closely to eliminate obstacles to flexibility and ultra-fast-responsive management strategies.

System Interdependence

By some estimates, the Air Force provides logistics, maintenance and sustainment support for about 7,000 aircraft and manages nearly $35 billion in inventory of reparable spare parts. The inventory of avionics components alone is estimated to be about $19.2 billion, roughly 55% of the total. The sustainment system is very complex, with a variety of subsystems that interact in numerous ways which are often not fully understood by participants in the system's daily operation and management. While staffed by very able people dedicated to the task of making the system run effectively, there is clearly a lack of understanding of the overall system by people at various hierarchical levels.

Our analysis indicates that the sustainment system is characterized by a high degree of interdependence linking together numerous "stove-pipe," multilayered , nested organizational structures where the nature and extent of the relationships among the various components, as well as the interactions between the system as a whole and its external environment, are known only imperfectly. By way of quick illustration, it may be noted that the "organic" depots at the various Air Logistics Centers (ALCs) , taken together as a public enterprise, are embedded within a large and complex institutional, organizational and management structure spanning the AFMC, the MAJCOMS, DLA and reaching well into various other parts of the DOD. The sustainment system, nested within the Air Force and more broadly within the Department of Defense, also cuts across and encompasses a substantial segment of the aerospace industry.

Under the two-level maintenance system the Air Force currently manages, spares are stocked at the first-echelon "retail" sites (i.e., operating bases) and also centrally at the "wholesale" sites (i.e., depots). The operating bases provide immediate repair support for the various commands, such as the Air Mobility Command (AMC) and the Air Combat Command (ACC). The wholesale sites, comprising the "organic" depots at the Air Logistics Centers (ALCs) as well as commercial providers of contract repair services, repair and maintain failed components that are not base-reparable and also serve as major resupply centers for the bases. The functional relationships among the numerous organizational entities are complex, multidimensional, and virtually impenetrable. The multi-echelon supply system the Air Force maintains encompasses a complicated set of behavioral relationships that are difficult to trace let alone predict with any accuracy.

The Air Force currently has five major depot level repair and maintenance centers: the Sacramento Air Logistics Center (ALC) at McClellan AFB in California, San Antonio ALC at Kelly AFB in Texas, Warner Robins ALC at the Warner Robins AFB in Georgia, Oklahoma City ALC at Tinker AFB in Oklahoma, and Ogden ALC at Hill AFB in Utah. Both the Sacramento and San Antonio ALCs are scheduled for closure in July 2001 as a result of the Base Realignment and Closure (BRAC) process of 1995. The ALCs perform repair, overhaul and modification of aircraft, missiles, engines, electronic components and other major items in the Air Force inventory. The AFMC depot maintenance capability has been critical to the successful accomplishment of the Air Force's wartime mission of ensuring high-level combat readiness, including its need to have "surge" capability to meet wartime mobilization requirements.

Our emphasis on the high degree of interdependence characterizing the sustainment system seeks to highlight four important issues. The ***first*** is that there is widespread evidence of local optimization going on to the detriment of global optimization. This is made abundantly clear in numerous site-visits to many parts of the sustainment system, including both the "wholesale" and "retail" sites as well as to the DLA. At the local level, people are making decisions that make sense for their part of the system but may prove counterproductive for the system as a whole. The pervasiveness of cannibalization at the squadron level, reflecting the logical outcome of difficult local choices and tradeoffs, are more generally indicative of existing incentive structures and pricing regimes. In a highly interdependent system, local optimization behavior can have often untoward and sometimes quite harmful effects at the system level.

The ***second*** issue concerns the definition of appropriate performance metrics, as well as the identification of best practices that could help improve systemwide performance. Many of the metrics currently used drive behavior towards local optimization. This calls for the development of a cascading chain of multi-linked metrics, since such a system does not currently exist. Metrics being used in the system in general do not appear to be internally consistent, nor do they gauge measures of successful performance. For example, DLA uses percentage of part requests filled immediately, which bears a tenuous relationship to metrics used at the wing or squadron levels, such as availability of mission-capable aircraft.

The ***third*** issue relates to the definition and choice of best practices to improve system efficiency and responsiveness against a background of what appear to be excessive transaction costs characterizing this highly interdependent system. We hypothesize, first, that the total cost of the sustainment system is poorly understood and measured. Budget allocations do not fully measure the true cost of supporting the warfighters. This includes the considerable costs of coordination within the system, measured against comparably complex organizations. A useful insight offered by modern transaction cost theory from economics is that analyses of internal, as well as external, costs of both production *and* coordination can provide a framework for making economically efficient choices between *markets* (i.e., outsourcing repair services to outside organizations, such as commercial enterprises) versus *hierarchies* (i.e., vertically integrated production within the enterprise). Typically, with emphasis placed on costs of providing specific types of repair services (e.g., engines, avionics, landing gears), the larger issue of systemwide *coordination* costs associated with these services are either given insufficient attention or are altogether ignored.

The *fourth* issue relates to our general observation that the sustainment system is clearly stressed. Budget cutbacks, against a backdrop of heightened readiness requirements and deteriorating aircraft availability rates, have resulted in stressing the existing repair facilities, resources and personnel. Large numbers of highly qualified technical personnel have exited the system, finding more rewarding career opportunities elsewhere. In such a highly interdependent system, the impact of such a stress requires close attention and concern, particularly in terms of further likely degradation of systemwide performance.

System Dynamics

Earlier we had discussed the dynamic nature of complex open systems, in the sense that they are subject to continuous change and adaptation, and drew attention to the importance of self-learning (organizational learning) as a critical enabler of successful adaptation. This discussion can now be more directly related to the sustainment community. So far, our emphasis on system characterization has decidedly concentrated on key system characteristics associated with maintenance and repair operations within the context of the larger objective to maximize aircraft availability. Here, we would like to draw a sharp distinction between a *static* view sustainment, with its heavy emphasis on repair and maintenance of fielded systems aimed at having them available and ready to meet existing mission requirements, and a more *dynamic* view of sustainment stressing continuous technological enhancement of fielded systems, as an integral part of the repair and maintenance process, as well as the design of new systems for optimal lifecycle sustainment.

To be sure, current initiatives to improve the efficiency and responsiveness of the sustainment system will continue and will perhaps accelerate. We believe, however, that the central longer-term dynamics of change affecting the sustainment community will be driven by a historic shift in the traditional sustainment mindset and practice. Hence, we stress the central importance of taking the type of dynamic view of sustainment just outlined towards the longer-term goal of delivering best lifecycle value to the warfighters. Best lifecycle value means delivering weapons systems to the warfighters at the right time and at the right price offering best lifetime value in terms of mission effectiveness, performance and lifecycle affordability, as well as in terms of ensuring on-demand cost-effective lifetime support services, efficient operational readiness, and enhanced mission capability through continuous technological sustainability.

Nearly 30% of DOD's annual budget is currently devoted to operations and maintenance. It has been estimated that overall DOD flying hour costs have risen by almost 70% between 1994 and 1998. In 1998 the Air Force is estimated to have spent $2 billion more to fly the same number of aircraft the same number of hours than in the previous year. The average age of the Air Force fleet is expected to increase from 20 years in 1999 to roughly 32 years in 2012. Under current funding plans, it is also projected that at no time between now and 2050 will the average age of the total Air Force fleet begin to drop. Subsystems and components of the aging aircraft fleets will fail more frequently, parts will become obsolete and will become more expensive, and previously unseen problems may well become commonplace.

The problem of parts obsolescence and diminishing sources is causing serious discontinuities in the flow of serviceable assets into the Air Force's product support pipeline. The problem, becoming progressively worse over time, is reducing the availability of aging aircraft systems and may be posing a growing threat to national security. Thus, while in the near-term (e.g., the next few years) significant efficiency gains can be achieved in overall operations and maintenance activities, over the longer-term modernization through technology is essential for achieving lasting cost savings. In addressing the problem of aging aircraft systems, significant improvements need to be made in ensuring that the military can take advantage of rapid, modern, technological developments through on-demand manufascturing (ODM), both within and outside the government, and other initiatives.

In an environment of rapid technological changes, a fundamentally new and different approach is needed to address the Air Force's sustainment requirements in the future marked by a mounting imperative to retain and enhance availability, readiness, and mission effectiveness of the Air Force's aging weapon systems.

Based on our preliminary research thus far, we would like to convey our strong observation that there does not appear to be a coherent vision and roadmap throughout the military that specifically and proactively addresses technological sustainment issues associated with aging aircraft systems. More generally, beyond the issue of aging aircraft systems, there appears to be a lack of a proactive, integrated, continuous technological refreshment strategy at the DOD level as well as within the Air Force directly connected to the on-going repair and maintenance operations to take full advantage of technology development initiatives within the government as well as rapid technological advances in the commercial sector. The current Air Force product support efforts appear fragmented and seem to concentrate mainly on repair and maintenance of fielded systems, while the current modernization through spares strategy does not seem to go far enough towards satisfying what is needed.

Recognizing the enormity of the challenge, the Air Force has started to fashion a structured strategy to address the problem in a proactive way. This encompasses the flexible sustainment approach being promulgated pursuant to the Joint Aeronautical Commanders' Group (JACG) guidelines to implement the Performance-Based Business Environment (PBBE) initiatives. Flexible sustainment, at least on paper, stresses the use of open systems specifications and standards to reduce lifecycle costs through supportability analyses employing a systems engineering process, reliability-based logistics decision process for existing systems aimed at reducing the cost of operations and support costs, and technology insertion throughout the lifecycle employing trigger-based asset management. Also, in this connection, the current efforts being made within the Air Force Research Laboratory (AFRL) to address aging aircraft issues herald an important step forward.

We make these points also to underscore a surprising finding: The Joint Warfighting Science and Technology Plan (JWSTP) is clearly concerned about DOD's general lack of awareness of overall logistics and sustainment performance measurement models, simulations, metrics and tools to provide joint readiness feedback to commanders, as well as about a deficiency in the area of overall logistics visualization. It would seem difficult to develop effective technology development initiatives for product support if there is a lack of the tools, metrics and capabilities needed for gauging the success, failure or overall impacts of these initiatives.

Meanwhile, although the current Air Force Source Of Repair Assignment Process (SORAP) seems to work well in reflecting the statutory limitations that have been placed upon source selection for repair and maintenance services, it probably needs to be broadened and updated to meet future sustainment needs and goals. For example, it might be designed to deal more fully with repair requirements associated with components affected by rapid technological changes and might further encompass proactive planning for the evolving longer-term support needs of individual weapon systems. Also, more immediately, there is a need to provide a consistent framework for making source-of-repair decisions. This can be accomplished by clarifying some of the inconsistencies introduced by recent legislation, such as those involving definitions of core, cost, readiness and sustainability factors. At a minimum, the SORAP could better reflect current public-private arrangement options that already exist and are legally sanctioned, rather than stipulating a narrow choice between an organic source and a private contractor.

Ultimately, no matter who is providing support for a given weapon system or specific components, the DOD, having a custodial responsibility for the nation's warfighting assets, will have to be a vigilant manager of the overall sustainment process. This will involve ensuring a robust science and technology base meeting national defense requirements, selecting sources of repair, and building a "win-win" public-private sustainment capability for providing agile combat support for the warfighters.

NEXT STEPS

The initial top-level system characterization presented in this paper can now be placed in its larger context, by outlining the next steps in the larger research task. The task addresses the following key issues and questions.

- What are the major characteristics of the Air Force logistics and sustainment system?
  - Customer requirements
  - Functions, operations, processes and activities
  - Technical and business practices
  - Organizational entities and structures
  - Supplier networks
  - Critical interactions and linkages among major system elements

- What are the critical obstacles and constraints to improved system performance?
  - Policy environment, laws, regulations and procedures
  - Incentive structures
  - Organizational issues

- What are the major strategies and measures for achieving transformation of the current sustainment system?
  - Best practices for system integration and optimization
  - Lean and agile combat support system.

The task pursues a three-phase research agenda: system characterization, system integration, and system optimization.

Phase I: System Characterization

- Top-level system characterization (functions, organizations, processes, metrics)
- Key interactions (static, dynamic)
- Systemic constraints
- Near-term opportunities for performance improvement

- **Initial system characterization**

  - ⇒ Customer requirements (goals, objectives, metrics)
  - ⇒ Key system characteristics
  - ⇒ Choke points

  - ⇒ Near-term opportunities for change: initial identification of promising best practices applicable to sustainment

- **Focused system characterization**
  - ⇒ *Customer requirements (goals, objectives, metrics)*
  - ⇒ Key system characteristics
  - ⇒ Interim opportunities for change:identification of promising best practices applicable to sustainment

Phase II: System integration

- ➢ Sustainment value stream mapping
- ➢ Identification of major sources of waste and inefficiency
- ➢ Major impediments to system adaptability, responsiveness and flexibility
- ➢ Goals, objectives and metrics: interim strategies for system integration and performance improvement

- **Sustainment value stream mapping**
  - ⇒ More detailed analysis focusing on representative weapon systems & components (support processes, flows, interactions)
  - ⇒ Identification of major sources of non-value added activities, constraints and issues

- **Strategies for system integration and performance improvement**
  Realignment of:
  - ⇒ Key functions
  - ⇒ Interfaces
  - ⇒ Processes
  - ⇒ Organizational structure

Phase III: System optimization

- ➢ Definition of future lean and agile combat support system

- ➢ Lean sustainment transformation roadmap
- ➢ Implementation guide and decision-support tools

- **Definition of future lean and agile sustainment system**
  - ➢ New lean and agile combat support paradigm
  - ➢ Dynamic technology refreshment of aging weapon systems
  - ➢ Design for sustainment and best lifecycle value
  - ➢ Open architecture design strategies
  - ➢ Multiorganizational/multinational interoperability
  - ➢ Integrated supplier networks
  - ➢ Information infrastructure for electronic integration of the sustainment system

- **Lean transformation roadmap**
  - ➢ Implementation strategies and steps
  - ➢ Decision-support tools.

As indicated earlier, while initially the main thrust of the System Characterization and Transformation task is to develop an improved, systematic, understanding and characterization of the sustainment system, over the longer-term it is anticipated to provide an integrative framework for the full spectrum of research activities within the Lean Sustainment Initiative.

POTENTIAL IMPACT ON AIR FORCE SUSTAINMENT SYSTEM EFFICIENCY AND RESPONSIVENESS

This task is expected to have a significant long-term impact on the effectiveness and efficiency of the Air Force logistics and sustainment system by helping to develop and implement:

- Strategies for near-term system integration and performance improvement
  - ⇒ Interim guiding principles and methods
  - ⇒ Identification of "low-hanging fruit" opportunities for improvement
  - ⇒ Initial identification of best practices

- Longer-term lean transformation roadmap & decision-support tools
  - ⇒ Clear and consistent goals, objectives and metrics
  - ⇒ Strategic public-private partnerships
  - ⇒ World-class business practices (business processes, financial management, contracting practices)
  - ⇒ Synchronized, efficient and responsive repair and maintenance operations
  - ⇒ Proactive and coordinated response strategies for continuous technological refreshment of aging weapon systems
  - ⇒ Open architecture design strategies and platforms for multiorganizational/multinational interoperability, continuous upgradability, and best lifecycle value to the warfighters
  - ⇒ Lean organizational structures
  - ⇒ Integrated supplier networks
  - ⇒ Streamlined government policies and procedures
  - ⇒ Seamless information system.

CONCLUDING REMARKS

This paper has been designed to convey a quick summary of the proposed conceptual framework for characterizing the Air Force sustainment system and for giving an overview of initial top-level system characteristics by employing this framework. Our preliminary observations about the sustainment system, together with some early suggestions or recommendations, are offered in the spirit that they may serve as working hypotheses that can be pursued in a structured manner and in more detail in the very near future. We believe the approach outlined in this paper offers great promise for guiding future research activities. More importantly, the type of systematic, research-based, process now underway should pave the way for developing concrete strategies, actions, implementation roadmaps, and decision-support tools aimed at directly benefiting the sustainment community in meeting its difficult challenges ahead.