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## Transforming U.S. Army Logistics: A Strategic Supply Chain Approach for Inventory Management

Greg H. Parlier, PhD, PE

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A Strategic “Supply Chain” Approach for  
Inventory Management**

**by**

**Greg H. Parlier, PhD, PE**

**The Institute of Land Warfare  
ASSOCIATION OF THE UNITED STATES ARMY**

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## Foreword

Fully engaged in the Global War on Terrorism, the U.S. Army also is committed to a comprehensive and ambitious transformation. However, without an enabling transformation in logistics there can be no Armywide transformation.

This paper introduces and presents a systems approach guiding an ongoing project that addresses many of the significant challenges confronting logistics transformation. The focus is on inventory management policy prescriptions illuminated through the prism of an enterprisewide supply chain analysis emphasizing Army aviation systems. This paper starts with a summary of recent trends for background, then presents a multistage conceptual model of the logistics structure and explains supply chain concepts in terms relevant to logistics transformation. Major sections focus on analysis, synthesis and integration, design and evaluation, and management. The multistage model is used to systematically analyze major organizational components of the supply chain, diagnose structural disorders and prescribe remedies. Next, integration challenges are addressed using cost-benefit perspectives which incorporate supply chain objectives of efficiency, resilience and effectiveness. A section on design and evaluation proposes an “analytical architecture” consisting of an “engine for innovation” and four complementary modeling approaches, collectively referred to as “dynamic strategic logistics planning” to guide logistics transformation. Finally, a thematic approach is used to address key strategic management challenges associated with transformation: organizational design, management information and decision support systems, strategic alignment for a learning organization and workforce considerations including human capital investment needs.

The author concludes that as the U.S. Army transitions toward a readiness-focused force, the logistics piece of the force likewise needs to transition. Currently, it does not know how to transition because it has not sufficiently measured the true effectiveness of the inventory and supply system. This paper provides not only an argument for pursuing such measures and a resulting transformation, it also provides a framework in which to achieve both.



GORDON R. SULLIVAN  
General, United States Army Retired  
President

September 2005



# **Transforming U.S. Army Logistics: A Strategic “Supply Chain” Approach for Inventory Management**

## **Introduction**

Fully engaged in the Global War on Terrorism, the U.S. Army is simultaneously committed to the most ambitious and comprehensive reengineering endeavor in its history. The early intellectual stages of this effort, universally known by the ubiquitous term “Army Transformation,” clearly revealed a crucial need to transform logistics concepts, organization, technology and culture to improve strategic response, force projection and sustainment. Thus, as the organization’s then-top logistician noted, the Armywide “transformation of organizations, processes, doctrine and culture demands a corresponding transformation in sustaining those organizations.”<sup>1</sup> Fundamentally, without a transformation in logistics there can be no Army Transformation.

## **Background**

*Why am I still throwing billions down this black hole called spares?*

General Eric K. Shinseki, Chief of Staff, U.S. Army<sup>2</sup>

## **Persistent Challenges**

In January 2005 the Government Accountability Office (GAO) identified the Department of Defense (DoD) “supply chain management” as one of 25 activities across the entire federal government that is at “high risk” and in need of “broad-based transformation.”<sup>3</sup> This is not a new observation. Indeed, since 1990 GAO has identified DoD inventory management as “high risk” because “management systems and procedures were ineffective and wasteful [and] the military services each lack strategic approaches and detailed plans that could help mitigate spare part shortages and guide their many initiatives aimed at improving inventory management.”<sup>4</sup> This clearly has been a long-term persistent problem, especially for the Army, and is directly attributed to an inability to link investment in spare parts inventories to weapon system readiness. Consequently, the Army is not capable of reporting to Congress how additional investments in spare parts would increase readiness. The Army contends that it cannot do so because no direct correlation exists between spare parts investment levels and the resulting impact of those investments on system readiness due to other factors such as maintenance capacity and training requirements.<sup>5</sup>

This persistent inability to relate strategic resource investment levels to readiness-oriented outcomes continues to have serious consequences for the tactical warfighting Army. Recent operational experience further asserts an urgent, compelling and chronic need for improvement. After-action reports (AARs) from Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF) indicated the hierarchical stovepipe supply system was too slow and inflexible to adequately support operations. Demand forecasts were determined by an inflexible and outdated requisition process that relied upon World War II-era wartime and even current *peacetime* consumption rates. One Army AAR stated that OIF success “stemmed more from luck than design.”<sup>6</sup> Michael Wynne, then Principal Deputy Under Secretary of Defense responsible for logistics policy, stated, “Whether push or pull, our current logistics are reactive. . . . [We have] an industrial age vendor struggling to satisfy an information age customer. Reactive logistics—the old logistics—will never be able to keep up with warfare as we know it.”<sup>7</sup> The Army’s chief logistician acknowledged “we weren’t as effective as we could be,” while GAO estimated that at least \$1.2 billion worth of supplies were lost during the deployment and follow-on operations.<sup>8</sup>

The Army, through its new Single Army Logistics Enterprise (SALE) project, is also investing heavily in an effort to fully capitalize upon the enterprisewide promise offered by information technology (IT). The scope of this enterprise resource planning (ERP) effort is believed to be the largest and most complex undertaken so far. Although enormous sums have been invested by the corporate world in IT-based enterprise resource planning, these investments have had mixed results.<sup>9</sup> Emerging evidence suggests dramatic improvements in performance and competitiveness can be achieved, but this success has been limited to those companies that have applied IT to an existing foundation of mature, efficient and appropriate business processes. Simply procuring information systems alone, especially ERP solutions, cannot overcome the lack of such a foundation. In fact, the evidence suggests that such attempts not only fail to achieve any performance increase—despite large and lengthy investment efforts—but actually result in reduced performance for those companies pursuing an IT-centric strategy.<sup>10</sup>

## Purpose

*Our transformation process focuses not only on technological innovations; we are looking equally critically at changes to current doctrine and organizational processes that will enable Transformation. Change must occur quickly, and accelerating change requires extricating ourselves from antiquated cycles and processes.*

General Paul J. Kern, Comanding General, U.S. Army Materiel Command<sup>11</sup>

Although countless great ideas and technology initiatives have been offered to support Army logistics transformation,<sup>12</sup> the task for the analytical community supporting the Army is to recognize and fully comprehend the fundamental nature of this challenge, then develop and offer a strategic approach and supporting analytical architecture that will guide the Army through this transformative period. This paper introduces and summarizes a comprehensive systems approach guiding an ongoing project addressing significant challenges confronting logistics transformation.<sup>13</sup> Conditions that motivate this research and analysis include:

- the changed nature of the geopolitical landscape resulting in the Army’s transition to an expeditionary, capabilities-based, globally deployable force;
- the opportunity to consider, adapt and extend, where appropriate, integrating “supply chain” design, management and analysis concepts and principles driven by increasing competition in the corporate world;
- a clear understanding of the enabling potential offered by information systems technology and so-called IT solutions;
- the recent DoD mandate to adopt performance-based logistics (PBL), a major change in defense logistics management philosophy; and
- an obvious and compelling need presenting a unique opportunity to develop and implement an analytical architecture, in conjunction with a newly emerging strategic management paradigm, to guide logistics transformation within a resources-to-readiness framework.

## **Scope**

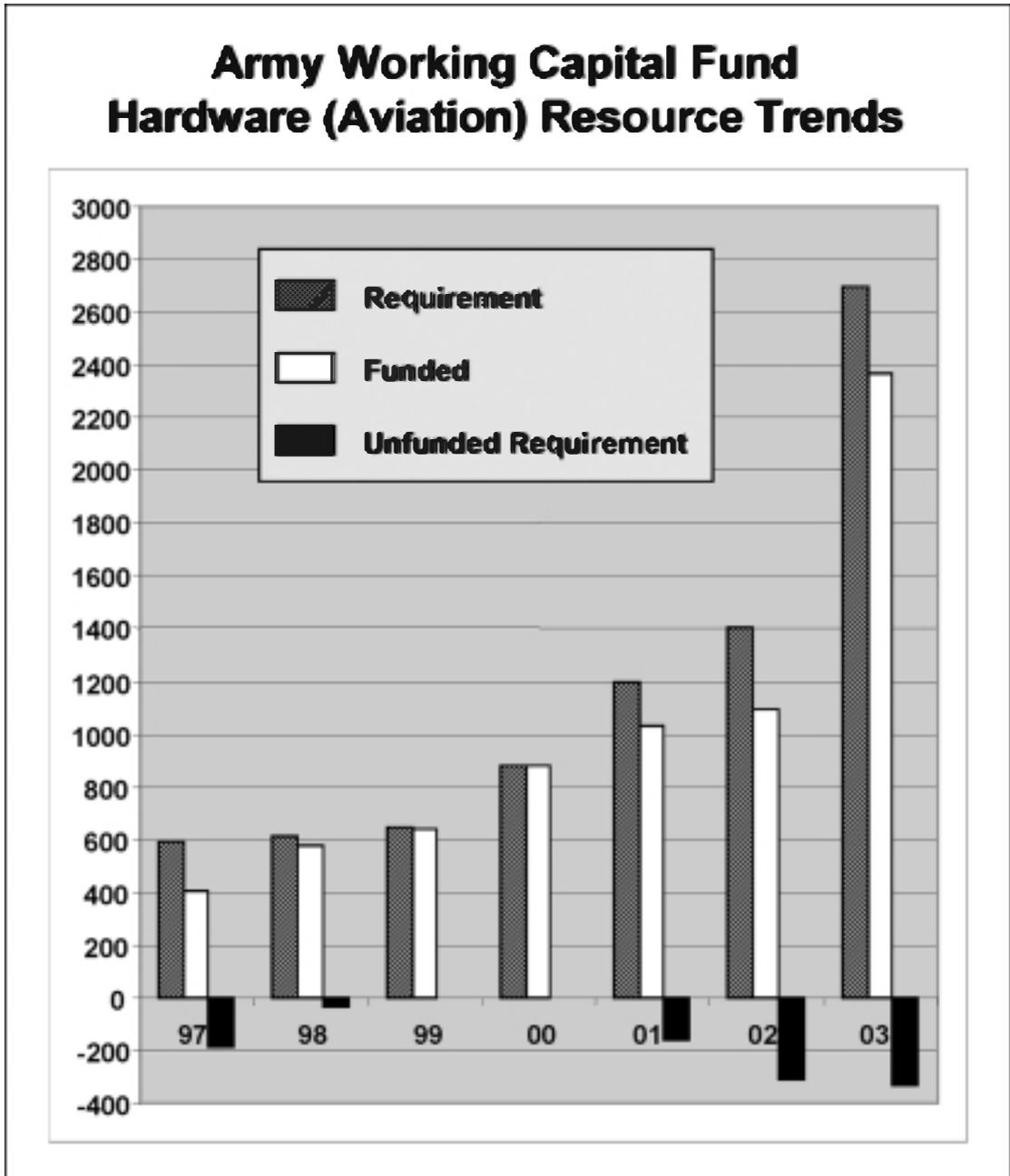
Currently sponsored by the Army Aviation and Missile Command (AMCOM), this project involves several supporting organizations both within and outside the Army and DoD. Although the project initially focused on aviation-specific Class IX (spare parts and components) inventory management as a test bed, its goal is to develop a prototype that will provide the foundational analytical architecture that would guide and accelerate Army logistics transformation. The Army’s global logistics operation is a tremendously complex and dynamic system, and a central component of even larger DoD and joint logistics operations. This system consists of a wide variety of highly variable product flows, extensive management information systems, considerable maintenance and supply infrastructure, globally dispersed transportation assets, several command and management agencies, countless vendors, suppliers and original equipment manufacturers (OEMs), and supporting financial management processes that track tens of billions of dollars annually.<sup>14</sup> Despite the initial euphoria over remarkably successful combat operations in OEF and OIF, symptoms of ailing and inadequate logistics support operations have become increasingly apparent. This paper does not dwell on these symptoms, which are outlined and detailed in several official and public reports, but rather endeavors to address, or diagnose, the underlying root causes and associated effects—the “illness”—that are manifesting in these symptoms now that this crucial but complex system has been substantially stressed. While acknowledging the numerous, interacting dimensions to this endeavor, the focus of this project is primarily, although not exclusively, on inventory management policy prescriptions illuminated through the prism of an enterprisewide supply chain analysis.

## **Project Overview**

### **Background—The Immediate Problem**

Despite exponential growth in both spare parts requirements and investment over the preceding five-year period, unfunded requirements (UFRs) and associated back orders had been growing

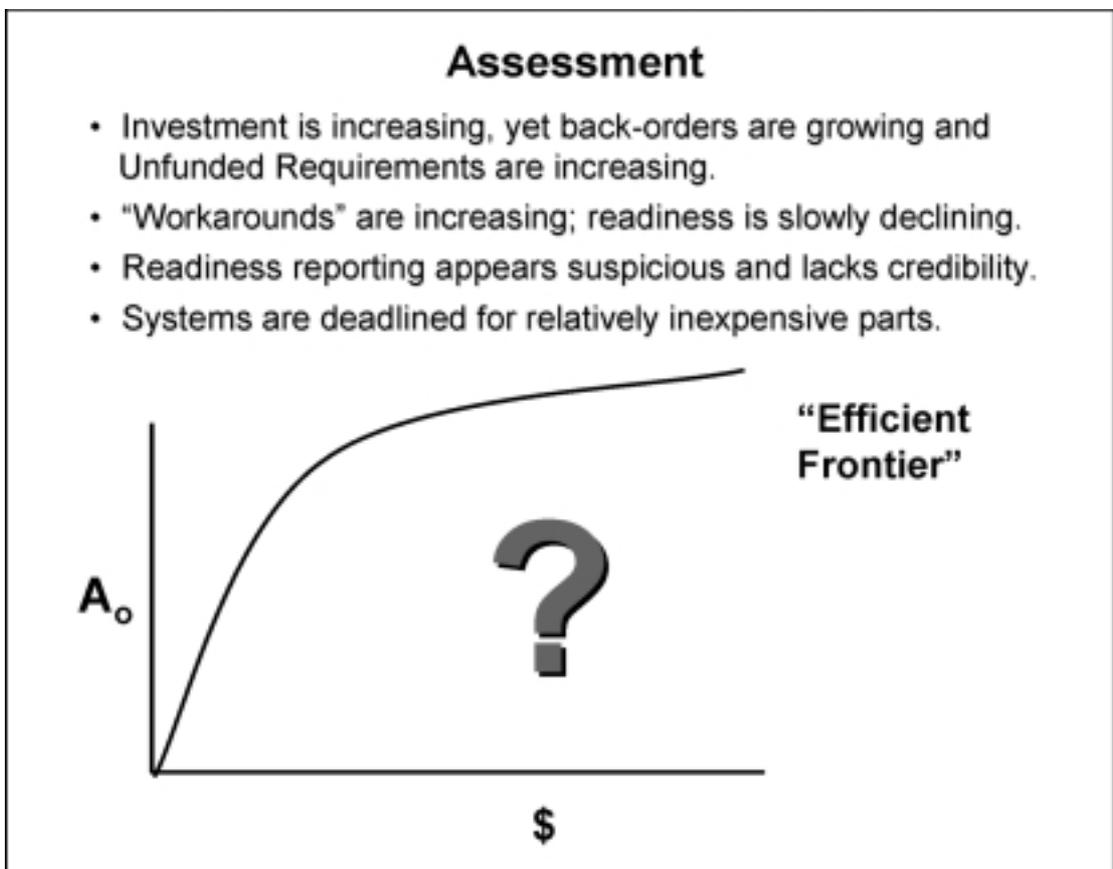
dramatically. In fact, at the beginning of Fiscal Year (FY) 2003, prior to OIF, the cumulative UFR for aviation spares alone was in excess of \$1 billion (figure 1). Readiness reports had been relatively steady, though slowly declining. However, skepticism in the accuracy of these reports was growing. For example, during FY 2001 while randomly inspecting units reporting 90 percent readiness or better, the U.S. Army Forces Command (FORSCOM) Inspector General (IG) found actual readiness in these units to be 30 percent to 50 percent lower than reported.<sup>15</sup>



**Figure 1**

Although tactical-level “work-arounds” in the field were also known to be increasing, it was not clear what impact fully funding the growing spares budget shortfall might have in terms of an incremental increase in actual readiness. Long depot repair cycles and procurement lead times are associated with many of these components, and both obsolescence issues and diminishing sources of supply characterize increasingly aging Army rotorcraft fleets. At the same time another worrisome pattern seemed to be emerging as, increasingly, major weapon systems across the Army were being rated non-mission capable due to a lack of relatively inexpensive spare parts. The Army was engaged in OEF in Afghanistan at the time. The growing fear, just a few short months prior to initiating OIF, was that significant additional stress on helicopter fleets could result in dramatic and sustained readiness deterioration in terms of aircraft operational availability (Ao).

The combined effect of these trends, at worst, portrayed an organization facing the proverbial death spiral: decreasing performance in the face of rapidly escalating costs at a time of potentially devastating consequences. At best, the actual point of efficiency in a tradespace measuring cost versus performance was simply unknown (figure 2). Despite the uncertainty in the existing logistics operating environment, magnified then by the anxiety of anticipated additional combat operations, an awareness was growing that these trends could not be sustained was growing.



**Figure 2**

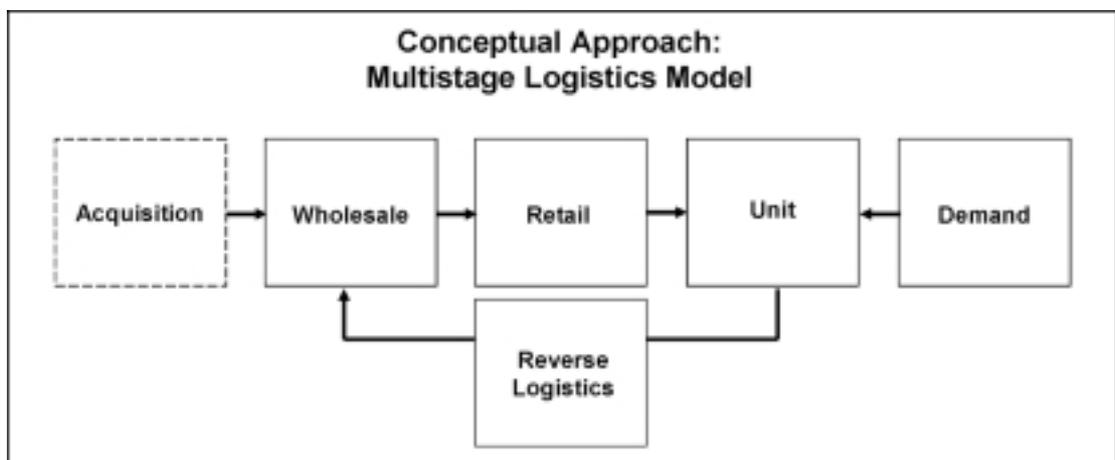
Major AMCOM concerns, expressed in the fall of 2002 when these conditions existed, were, “How much should we be investing on spares at the wholesale level to meet Army aviation fleet readiness goals?” and “Are we spending our resources on the right things?”

### Conceptual Approach—Current Logistics Structure

This paper presents a systems framework that is guiding the project. The purpose here is to present a conceptual multistage logistics model, explain the purpose and interdependencies of these particular stages, and summarize emerging analytical insight and supporting recommendations from various participating analytical organizations. This multistage model, a graphical simplification of the Army’s complex logistics structure (figure 3), consists of the following stages:

- a “unit” stage representing Army tactical organizations where readiness production actually occurs;
- a “demand” stage representing training requirements and operational missions;
- a “retail” stage representing installation and tactical supply support activities providing direct or general support to specific units;
- a “wholesale” stage consisting of the aggregate continental United States (CONUS) repair and supply depots managed by Army Materiel Command (AMC) and the Defense Logistics Agency (DLA);
- a “reverse logistics” stage representing the retrograde pipeline for depot-level repair components (DLRs), including, for example, turbine engines, transmissions and rotor blades for aviation systems; and
- an “acquisition” stage representing original equipment manufacturers and suppliers responding to the procurement and sustainment needs of the Army.

This multistage conceptual perspective, coupled with basic knowledge about the current state of logistics, reveals initial insight into the potential cause of challenges that have been

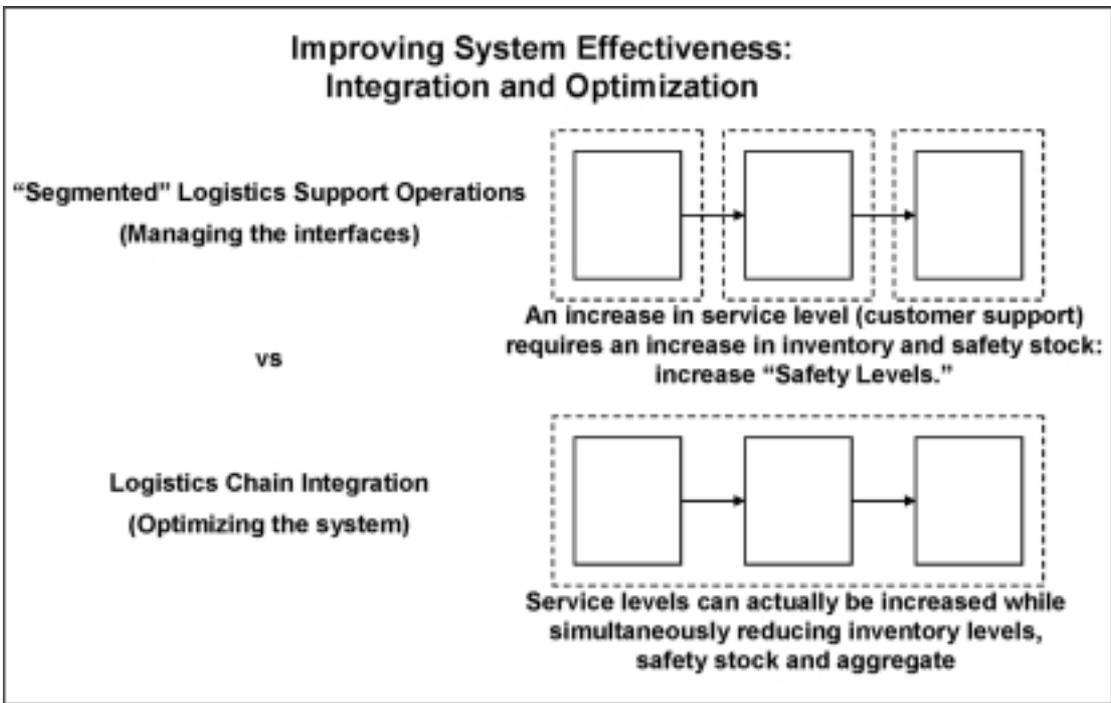


**Figure 3**

accumulating over time. For example, unlike the corporate sector—where consumer demand is well defined at the end of the supply chain and product consumption can be measured precisely and forecasted accurately—the “customer” here is unit readiness needed to meet operational mission requirements. What does not exist is a well-defined, empirically derived production function, or “readiness equation,” especially for Army aviation systems, that relates capital investment (including spares) and labor (maintenance support) to various aircraft performance standards necessary to meet training and mission requirements, i.e., the “customer demand.” Without it, efforts to forecast logistics requirements have been inaccurate and largely reactive, leading to uncertainty and variability induced into the larger logistics system at the point of consumption.

Another example is the existence of a “reverse logistics” or “retrograde” stage. Rare in the business world—where products normally are consumed by the market—this stage constitutes the “value recovery” effort to maintain, repair, overhaul, upgrade and return large subassemblies and replaceable units that are not “consumed” but “used” as capital assets. Although these items constitute only about 25 percent of the number of demand requisitions, they also represent more than 75 percent of total requisition value. Nonetheless, an underlying theory for retrograde operations has never been established to guide performance standards for the reverse pipeline and, as a consequence, the organizations responsible for the forward supply chain also are responsible for the reverse. Until recently, ability to measure delay time in the reverse pipeline did not exist, reflecting the lack of importance and priority this aspect of logistics operations historically received within the culture. Yet, this multistage conceptual model reveals the importance of viewing the retrograde stage, from a systems control theory perspective, as a feedback loop with obvious impact upon unit readiness. For every reparable component delayed in an unresponsive reverse pipeline—delay times are now measured in averages of several months—another like component must exist elsewhere within the forward supply chain or the retrograde feedback loop will degrade readiness output.

Finally, the multistage model also suggests configuration of the current logistics structure as a series of independently operating organizations, frequently with differing agendas and conflicting goals, struggling to manage the adjacent interfaces among them (figure 4). Various supply performance metrics have evolved over the years to manage these interfaces. However, these organizations did not have a clear view of their effect upon “readiness” production and could not relate their interface metrics to a readiness-oriented outcome. Consequently, they could not effectively correlate resource investment levels and coordinate policy decisions—both within the stages and across them—to achieve readiness goals. At best, the decisions within these organizational stages, which functioned as structural constraints on the overall supply chain, yielded only locally optimal solutions. Each of these organizations is, by definition, clearly dependent upon others; yet, paradoxically, they have not traditionally cooperated with one another in a closely coordinated manner. In addition to operational inefficiencies, these organizational constraints also induce counterproductive behavior due to cognitive limitations on the part of logistics managers, who naturally tend to undervalue elements of the supply chain they cannot see or control.<sup>16</sup> It is, therefore, not surprising that the existing logistics structure—largely a legacy system from an industrial age environment where “buffers” of stock were created to accommodate uncertainty, variability and organizational structure—was never designed to



**Figure 4**

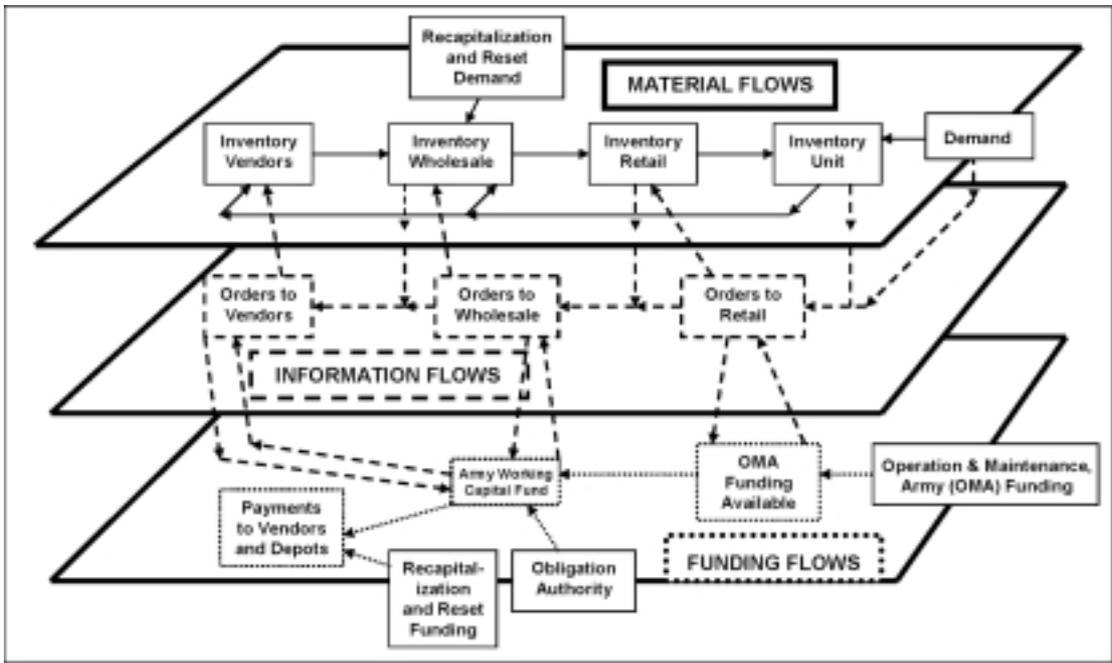
adequately address these growing AMCOM concerns expressed by the commanding general in 2002.

### **Application of Supply Chain Concepts—Analytical Foundation for Improving Logistics System Effectiveness**

The academic development of theory and subsequent practical implementation of supply chain management concepts in the corporate world offer valuable insight into Army logistics challenges. Two key concepts will be offered here. First, enabled by transportation planning and materiel management, logistics has traditionally been defined as the forward flow of materials from suppliers through a series of production and distribution stages to customers. More recently, supply chain design concepts and management theory expanded to incorporate two other flows through these logistics stages as well: demand information and cash flows back through the structure. This view of multiple information and physical flows interacting across templates (figure 5) then led to the second concept, now known as the “bullwhip effect.”

This bullwhip effect illuminates the enormous consequences of these independently operating stages and interacting templates on the system. Actual consumer demand is magnified at successive stages as a consequence of incomplete and delayed information rippling back through the supply chain, thereby causing amplification, oscillation and time lags of the original demand signal.

Known to management scientists since the early 1960s, this amplification of the fluctuation phenomenon in multistage systems has also been recognized in production systems.<sup>17</sup> However,



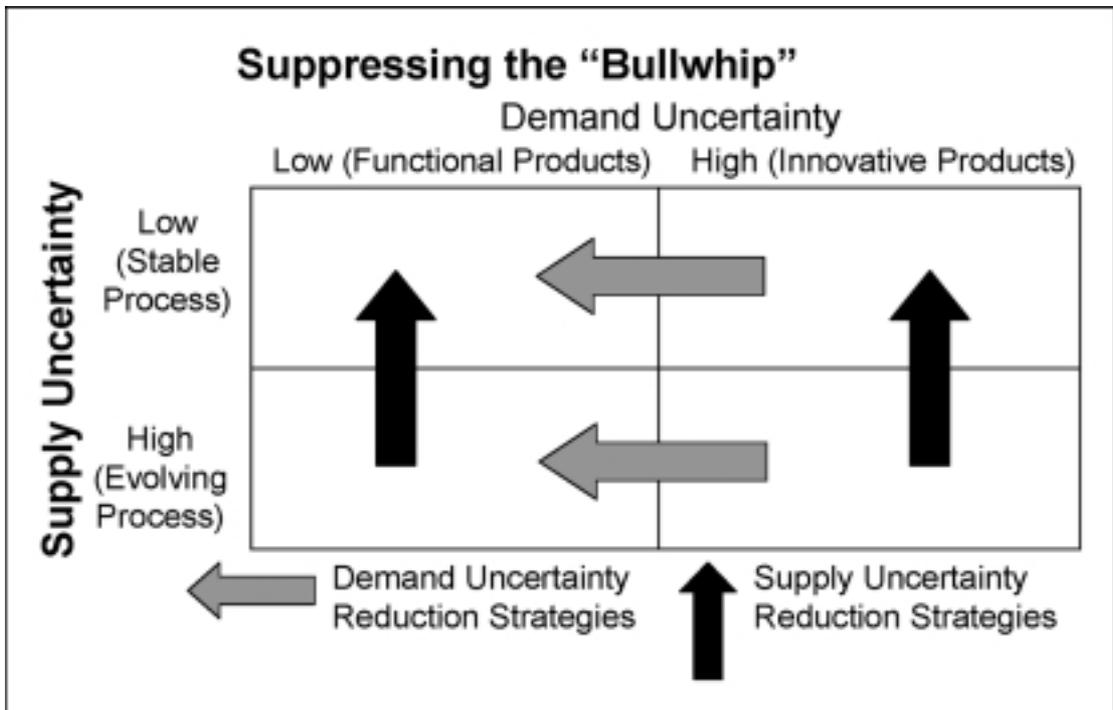
**Figure 5**

this induced, cascading variability, which necessitates greater inventory levels to accommodate such volatility, has only recently been quantified in the theoretical academic literature. Enterprisewide variability grows geometrically as the number of independent stages in the supply chain increases. By contrast the value of information sharing, access to centralized databases and collaboration across the stages also has been quantified and shown to dramatically reduce system variability and associated requirements for buffer inventory while actually improving performance by reducing “stockouts” (out-of-stock inventory).<sup>18</sup> Shared information and collaboration have the effect of collapsing several independent stages into only a few virtual stages. One example of implementing supply chain collaboration is referred to as “vendor managed inventory.”

In the commercial sector when a company faces pressures of excessive inventory, degraded customer service, escalating costs, declining profits or a poor return on assets, its supply chain may be out of control. Similarly, if a company is moving into new markets or new technologies, its supply chain must be appropriately aligned for new business opportunities, challenges and uncertainties. Despite the many new design concepts and management approaches intended to exploit the advantages of the Internet and IT, successful companies realize that an appropriate supply chain strategy must be tailored to meet the needs of its particular customers and market conditions. For example, a product with stable demand and a reliable source of supply should not be managed the same as one with highly unpredictable demand and an unreliable source of supply. A model to assist in selecting an appropriate supply chain strategy consistent with demand-side variability characteristics was initially developed by Marshall L. Fisher, then later extended by Hau Lee to incorporate supply-side variability characteristics as well.

This “uncertainty framework” (figure 6) illuminates the potential improvement in supply chain performance by adopting both “demand uncertainty reduction strategies” and “supply uncertainty reduction strategies.” The goal is to adopt techniques and policies that will reduce as much as possible aggregate variability in lead-time demand and choose an appropriate design to effectively accommodate resulting supply chain characteristics. In the business world, efforts to reduce the effects of demand uncertainty have focused on information sharing and supply chain collaboration. This provides enterprisewide visibility of actual customer demand and thereby reduces pernicious bullwhip effects. Methods to reduce supply-side uncertainty have included collaborative relationships, longer-term contracts with suppliers and the creation of supplier hubs to cut down supply risks in manufacturing lines. Lee has defined four resulting supply chain strategies that should then be aligned to product uncertainties (figure 7):

- “efficient” supply chains—strategies aimed at creating the highest possible cost efficiencies by eliminating non-value-added activities, pursuing economies of scale and optimizing capacity utilization in production and distribution;
- “risk-hedging” supply chains—strategies that pool and share resources to reduce risks and increase safety stock to hedge against supply chain disruption;
- “responsive” supply chains—strategies designed to be responsive to the changing and diverse needs of the customer, including build-to-order and flexible, high-order accuracy mass customization processes; and



**Figure 6**

- “agile” supply chains—strategies that combine the strengths of “responsive” and “risk-hedging,” characterized as “agile” because they are responsive to unpredictable customer demand, but also minimize risks of supply disruption.<sup>19</sup>

The existing aviation logistics structure is indeed vulnerable to the bullwhip.<sup>20</sup> System dynamics modeling provides significant explanation regarding these death-spiral conditions characterizing the current environment. The analytical challenge now is to better understand Army logistics system hysteresis by first segmenting the logistics structure into stages, then identifying, understanding and attacking each of the root causes contributing to uncertainty, variability and inefficiency within each stage and across the system of stages. The stages can then be linked using network optimization methods, thereby relating resource investments to readiness-oriented outcomes with greater confidence. For example, Readiness-Based Sparing (RBS) uses a marginal analysis approach to generate a cost-constrained retail stock policy that optimizes the link between the retail stage and a desired readiness production level at the unit stage. By reducing uncertainty and improving efficiency within each stage and linking the stages using multiechelon optimization methods developed for large-scale, complex systems, logistics performance is moving toward the efficient frontier in a cost-availability tradespace as illustrated in figure 2 on page 5.

Analytical demonstrations, field experiments and testing are being used to quantify these major efficiency gain initiatives:

- development of a readiness equation for the unit stage;
- implementation of PBL concepts, including availability-based sparing and centralized risk pooling in the retail stage;
- use of empirically derived, operation-based forecasts for the demand stage; and,

		<b>Supply Chain Strategies</b>	
		<b>Demand Uncertainty</b>	
		<b>Low (Functional Products)</b>	<b>High (Innovative Products)</b>
<b>Supply Uncertainty</b>	<b>Low (Stable Process)</b>	<b>Efficient supply chains</b>	<b>Responsive supply chains</b>
	<b>High (Evolving Process)</b>	<b>Risk-hedging supply chains</b>	<b>Agile supply chains</b>

**Figure 7**

- reduction of the delay time in the retrograde stage for DLRs.

Then, working backwards through the supply chain from the point of readiness production, the stages can be linked together, conceptually using multiechelon optimization to leverage the links between stages so that “resources-to-readiness” investment decisions can be made with dramatically improved accuracy.<sup>21</sup> Return on investment (ROI) estimates then can be reliably performed, for the variety of proposed initiatives and cost-benefit assessments would enable this analytical architecture to guide an ambitious logistics transformation, consistent with a strategic plan for implementation by pushing the envelope of continuous improvement.

However, the great challenge for the Army’s unique supply chain strategy, referring back to Lee’s framework above (figure 7), is that it needs to not only be both efficient and effective, but also agile, responsive, adaptive and robust to accommodate both surges in demand and disruptions across the supply chain. What is needed is a logistics network that is efficient, effective and resilient. This project endeavors to assist the Army in achieving such a result through logistics transformation.

## **Multistage Approach—Analysis of Systemic Challenges**

### **Readiness Production Stage**

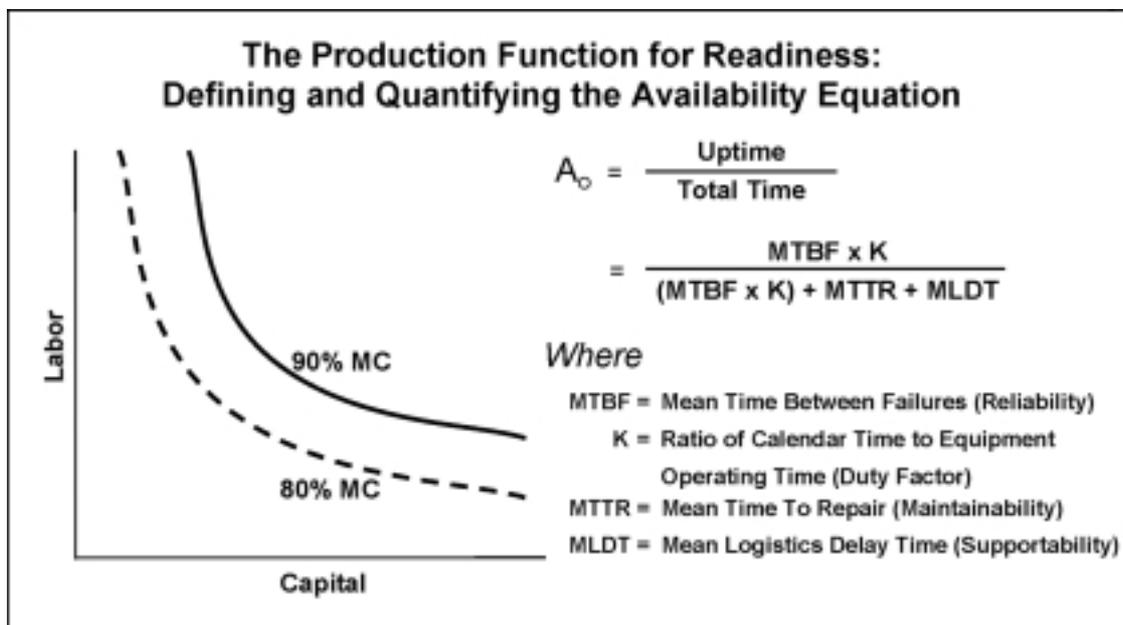
*Logistics can no longer be thought about as an annex to our operations plans. . . . It must be inherent in the plan . . . not a “wake-up call.”*

General Paul J. Kern<sup>22</sup>

Readiness reporting trends from the field were becoming increasingly worrisome by Fall 2002. Overall, short-term aviation readiness seemed to be holding, although longer-term trends suggested a slow yet noticeable decline. This apparently healthy state of tactical aviation units was partly illusion with controlled substitution masking a deeper readiness problem. Aviation commanders were increasingly resorting to controlled substitution to maintain acceptable readiness rates while compensating for an inventory system that could not keep up with the growing demands of aging aircraft fleets.<sup>23</sup> Nonetheless, the rate of non-mission capable (NMC) aircraft was persistently attributed to repair maintenance downtime (non-mission capable maintenance, or NMCM) rather than a shortage of spare parts (non-mission capable supply, or NMCS). These reported trends were not consistent with an already large and growing backlog of spares—for aviation alone the shortfall was nearly \$1 billion at that time—suggesting that the actual NMCS rates were considerably higher than reported. Another indicator for comparison was the fixed-wing aircraft NMC rates for both the Navy and the Air Force, nearly 50 percent of which was due to spares shortages compared to only about 10 percent reported for Army rotorcraft. These inconsistent trends are partially the consequence of an inadequately understood “production function” for Army aviation readiness.

In typical, large commercial-sector supply chains, products are created in accordance with a well-defined and highly refined production function describing the manufacturing process. Subsequent distribution occurs through international or national wholesale centers, then regional

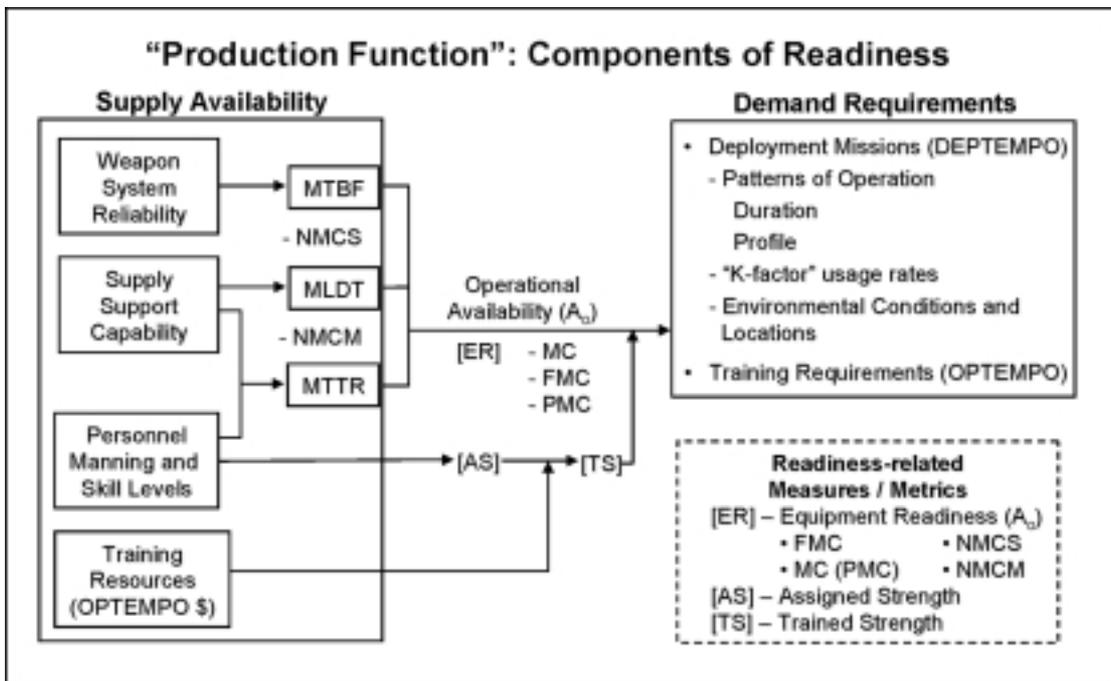
retail distribution centers and ultimately to customers who consume the product. In military spare parts supply chains, the consumption process also involves another production function—the creation of militarily capable and ready units available to execute the National Military Strategy. For Army aviation systems this production function, or “readiness equation,” is not yet well understood, in terms of traditional economics relating labor and capital to desired readiness production levels. These readiness levels are typically defined by aircraft Ao percentages (figure 8).



**Figure 8**

Consequently, because capital in the form of spare parts investments cannot be optimized to an unknown or uncertain readiness production function, numerous work-arounds occur that tend to substitute labor for capital. For example, increased maintenance man-hours are routinely incurred to compensate for requisition delays or shortages of parts by resorting to controlled substitution or cannibalization (figure 9). Emerging research results indicate this is occurring about 25 percent of the time across the Army’s aviation fleet.

This additional labor-intensive work-around demand, induced by spare parts shortfalls, exacerbates an already stressed existing labor supply of tactical-level mechanics. Army regulations specify manpower requirements for mechanics based upon maintenance standards.<sup>24</sup> Nonetheless, recent FORSCOM data clearly shows that the number of mechanics assigned to units and the amount of maintenance man-hours available are too low to meet these field-level maintenance requirements. This manpower shortfall equates to about \$300 million of annual unexecutable organic maintenance, of which 20 percent is accommodated through civilian maintenance contract support agreements, an increasing trend.<sup>25</sup>



**Figure 9**

A final condition that further clarifies and illuminates the compelling need for a production function—a readiness equation for Army aviation—is the universally acknowledged inadequacy of existing tactical-level databases to capture meaningful aviation maintenance and supply data.<sup>26</sup> Obviously, regardless of the sophistication and “fit” of mathematical models, any sincere effort to align Class IX demand forecasting to readiness targets is critically dependent upon supply and maintenance consumption data accuracy. As the Army seeks to improve its field data collection systems, especially for aviation, care should be taken to ensure that consumption data is not only captured to enable readiness production analysis and trends, but also processed in such a way that resupply can automatically be triggered, similar to point-of-sale collection and inventory reorder triggers in the consumer products industry.

### Operational Mission and Training Demand Stage

*We must operationally link logistics support to maneuver in order to produce desired operational outcomes.*

Les Brownlee, Acting Secretary of the Army,  
and General Peter J. Schoomaker, Chief of Staff, U.S. Army<sup>27</sup>

*Operations Research has also gradually lost much of its original empirical focus; modeling is now chiefly a deductive undertaking, with little systematic effort to test deductive claims against real world evidence.*

Stephen Biddle<sup>28</sup>

U.S. military strategy is evolving from the Cold War's "threat-based" force planning concept, with globally extended and forward-deployed, CONUS-reinforced forces, to an expeditionary capabilities-based, power-projection concept consistent with the changing geopolitical environment. This Modular Force structure is designed to conduct various types of operations, simultaneously and overlapping, across a wide spectrum of anticipated and unanticipated missions. Resources—including sustaining assets such as Class IX repair parts and components, associated combat service support organizations and doctrine—should be aligned to support these desired capabilities. Aligning resources with desired capabilities starts with a clear understanding of how resource usage factors for various expeditionary operations and locations differ from standard peacetime, home station training requirements. Currently, tactical operations planning involves deploying with a logistics support package optimized for peacetime training conditions or, in some cases, multiplying a standard peacetime quantity by a subjectively derived factor. At the strategic level, long-term resource forecasting to support program development usually involves averaging past demands over time (several years), location and mission types and extrapolating those average results as an estimate for future investment budgets. Clearly, a great deal of potentially useful information is not being considered in forecasts that aggregate averages across time, location and missions. This lack of an empirically derived, operation-based forecasting process also contributes to the large "safety levels" of stock incorporated into wholesale supply requirement objectives.

"Demand forecasting" refers to the quantitative method used for predicting future Class IX demand for spare parts generated by training requirements and operational missions. Reducing both demand uncertainty and variability at the point of consumption where readiness production occurs, and providing both understanding of causes and knowledge of effects, is crucial to reducing systemwide aggregate variability in lead-time demand. Theoretically, both average demand and variability in demand are confounded with supply-side effects that together interact to magnify system variability, thereby driving up the need for additional safety stock. Even though demand may be perceived as an uncontrollable variable, simply ignoring it and concentrating only on supply-side variance reduction efforts throughout the rest of the upstream supply chain will not achieve the dramatic performance improvements that are possible. Currently, however, the Army does not know what real demand actually is, partly due to the lack of a readiness equation described earlier. As a recent GAO report on defense logistics in OIF notes: "The logistics effort was weakened by long processing times for supply requisitions, which resulted in the loss of confidence and discipline in the supply system, the abuse of the priority designation process, and the submission of multiple requisitions."<sup>29</sup> As recent comments from a former senior Defense logistics policy official suggest, this "blindness to true demand" results in a "high cost of low trust."<sup>30</sup>

In the AMCOM supply chain project, the major initiative in this stage is focused on improved forecasting by borrowing concepts from market segmentation research and population polling statistics. "Stratified sampling" is a powerful variance reduction technique that enables accurate and precise estimates without the need for larger, more costly sample sizes typically required when using random sampling of a large and diverse heterogeneous population. Stratified sampling achieves these results by capturing and using more of the information in targeted homogeneous

subpopulations, or market segments. Not only can subpopulations offer more accurate and precise forecasts, but overall parameters for the entire, more diverse population can be more accurately predicted with far greater confidence (reduced variation).<sup>31</sup>

In the AMCOM application we are focusing initially on those intuitively derived factors (explanatory variables) that can or should be expected to affect Class IX consumption. These include weapon system type, training or operational mission category, geographic location and environmental conditions and system parameters including such factors as aircraft age. For example, the survey may find that aggregate flying hours contribute toward predicting spares demand in a training environment, but in certain types of operations flying hours do not contribute as much to the forecast as might the actual number of missions flown (sorties). We also will determine whether these factors are captured by existing data collection systems and to what extent, if any, they are incorporated into current mission and resource planning factors. We have developed a large experimental design to identify those significant cost and readiness drivers that either dominate or differ significantly across operational missions and geographic locations and how they may vary from peacetime training. Our major hypothesis states: “If empirically derived Class IX usage patterns, profiles and/or trends can be associated with various operational mission types, then both operational planning requirements and resource forecasting can be significantly improved to support a capabilities-based force.”

Fundamentally, this is an effort to capture the statistically significant factors influencing future demand using all of the empirical evidence of recent experience. We are optimistic because of the successful effort to dramatically improve casualty forecasting during the past decade. Previously, for example, medical planning factors were derived from attrition-based, theater-level campaign model casualty projections. However, when compared with actual empirical evidence from recent experiences of modern warfare, including the Persian Gulf War, these projections were over-predicting aggregate casualties, thereby creating unaffordable requirements for medical support force structure. Recent extensive, comprehensive analyses into the nature of modern warfare,<sup>32</sup> and the structure and patterns of casualties that result,<sup>33</sup> are yielding major improvements in forecasting accuracy and in designing more responsive, effective support requirements that, in many cases, reduce force structure investments. Both of these analyses, which challenged traditional views and standard practices, have been validated and corroborated by recent experiences in both Afghanistan and Iraq and are now being further refined and extended.

Similarly, through a systematic and analytically rigorous evaluation of the empirical evidence of past events, we intend to identify and verify patterns of use that will have significant predictive power for the future. Successfully developing this empirically derived, mission-based forecasting capability could lead to even more dramatic improvements in reducing demand uncertainty and variability. Research has shown that “demand lead times behave in a fashion that is exactly the opposite of supply lead times. In effect, an increase in demand lead time improves the system performance exactly like a reduction in supply lead time.”<sup>34</sup> This insight, coupled with the concept of “feed-forward” control from adaptive control theory, suggests that system output (e.g., Ao) can be positively affected “a priori.” Whereas conventional “feedback” processes can reduce the effect of a disturbance on output, it can do so only after the effect of the disturbance is seen. The concept of “feed-forward,” an anticipatory response oriented on predicting failure, is centered

on counteracting disturbances before they can impact output. These implications are significant even beyond the “sparing to mission” capability outlined above. For parts that are either failure prone or known to be nearing the end of their useful life, this suggests repair and replacement *prior to* executing a particular mission. This would enhance mission success by preempting failure—in a sense “inoculation”—thereby improving and extending Ao. In fact, this theoretical observation has been routinely practiced for many years by the 82d Airborne Division as they prepare and cycle their Initial Ready Company (IRC), Division Ready Force (DRF) battalions and Division Ready Brigades (DRBs) through a no-notice, global deployment alert process (“N-hour sequence”).

## **Retail Stage**

*We cannot afford to plan for future logistics by segmenting the logistics planning from the overall operations planning. . . . Customized packaging based on actual and operational needs enables responsiveness to future challenges.*

General Paul J. Kern<sup>35</sup>

The “retail stage” in this multistage logistics network model consists of globally dispersed Supply Support Activities (SSA) containing hundreds of Authorized Stock Levels (ASL) typically located near their supported battalion and brigade tactical units. Historically, the Army manages supply parts in ASLs based upon an item-level, demand-based stock policy: during a given period of time, if a minimum quantity of a particular part was ordered to meet an “add/retain” threshold, the part could be stocked at the prescribed level; in general, all parts were stocked according to the same rules, and no special considerations were given to either part cost or part impact on readiness.<sup>36</sup>

In recent years the Army has transitioned to a modified policy that does consider parts costs, although the categories used in this dollar cost banding policy are arbitrarily designated. This new stock policy resulted in steady improvement where it has been implemented.<sup>37</sup> Nevertheless, metrics used to assess this effectiveness are still supply performance focused, including satisfaction rates, accommodation rates and fill rates, rather than readiness metrics, including Ao. Consequently, developing consistent cause-effect relationships between retail investment levels and readiness-oriented outcomes continues to be almost impossible with no specific, objective function to optimize using either of these two currently mandated Army stock policies.

The fundamental purpose of any military inventory system is to sustain the supported force, in this case with aviation items. The true measure of inventory system performance should be the ability of that system to produce mission-capable aircraft, specifically maximizing aircraft availability. Traditional supply performance standards have focused on interface metrics (figure 4, page 8), especially fill rate, to gauge inventory system performance. This can yield misleading indications. Fill rate measures only what happens when demand occurs, whereas back orders also measure the duration of the shortage. Since back-order durations are not considered, the trade-off between short versus lengthy back-order durations is not measured. Nor does fill rate consider aircraft complexity, yet more complex aircraft require a higher fill rate than simpler aircraft to achieve a given Ao.<sup>38</sup> While a high fill rate may suggest healthy supply support, it is not directly related to the inventory system’s impact on end-item readiness. Conversely, a more

relevant and insightful indication of inventory system performance relative to a readiness-oriented outcome is the relationship between back orders (supply shortfall) and NMCS (Ao degradation due to supply shortfalls): as inventory system responsiveness improves over time, back-order rates should decline and both Customer Wait Time (CWT) and NMCS decrease accordingly with a positive effect upon readiness.

Historically, however, data scatterplots associating NMCS ratings with back-order rates are indeed scattered, showing essentially no relationship between the two, although fill rate metrics are, at the same time, within acceptable limits. It has been difficult to establish a correlation between back-order rates and readiness. Crucial parts that incur long delivery delay times, thereby impacting readiness, tend to be resolved at the tactical level through various work-arounds that increase maintenance labor workload. Recent evidence shows that as CWT increases for unscheduled repair at unit level, work-arounds likewise increase which, in turn, masks what otherwise would have been declining readiness. This compensating action at unit level is isolating readiness results from wholesale supply system performance rather than illuminating supply system ability to effect Ao. Consequently, managing the supply system to fill rate interface metrics actually precludes identifying and implementing meaningful cost-effectiveness choices within an investment-performance (readiness) tradespace. This must be corrected.

To both illuminate this managerial shortcoming and identify a better, outcome-oriented approach, the most important initiative in this stage has been the analytical demonstration and subsequent field testing of a retail stock policy focused on weapon system readiness for aviation performance rather than supply performance. For each repair part, this policy considers cost, frequency of use and contribution to readiness, then uses a marginal analysis approach to determine a minimum-cost ASL to achieve a desired system readiness goal. This method has been variously referred to as multiechelon technique for recoverable item control (METRIC), sparing to availability (STA) and RBS. The key difference between this method and others that focus on managing individual spare parts is the ability to adopt inventory policies focused on the end item, such as aviation rotorcraft, and readiness goals needed for those end items. This enables a systems approach that incorporates the differing contributions of all components across the entire supply chain rather than focusing on individual item supply performance interface metrics such as fill rate.

RBS enables the development of efficient solutions and establishment of relationships between ASL costs and weapon system availability. Relationships between resource investments and readiness outcomes can then be determined. Thus, in terms of the resources-to-readiness challenge, this is a crucial first step in optimizing the supply chain. If the initial link between the retail and unit stages has not been optimized to achieve tactical aviation readiness production goals, then the potential benefits of improving many other, more costly and inefficient upstream logistics network stages will not be fully realized. Although the item level approach may be simpler and easier to implement within existing ASL and wholesale supply control study procedures, it is not possible to know whether individual item decisions will achieve an acceptable level of readiness within budget constraints. Additionally, the item approach historically tended to use the same protection level (safety stock) regardless of costs, yet dramatic improvements in system performance have been demonstrated when these other factors are included.<sup>39</sup>

Although the Army has experimented with RBS starting more than a decade ago, it has never adopted the policy for routine use beyond initial spares packages for newly fielded systems. Additionally, the testing and experimentation was limited to ground-based systems. Our own RBS analytical demonstration first used UH-60 aircraft in the 101st Airborne Division (Air Assault), as shown in figure 10, and is currently a large-scale field test at Fort Rucker, Alabama, where nearly a third of the Army’s flying hours are executed at the Army Aviation School using several different aircraft types. This test clearly demonstrates the significant advantages of implementing RBS in the retail stage of the aviation supply chain. Extrapolating these results across all Army division-level retail ASLs, the Army Materiel Systems Analysis Activity (AMSAA) estimates the requirement objective (RO) would be reduced by several hundred million dollars, yielding potential savings that could then be applied, for example, against the growing backlog of back orders. An additional benefit obtained from RBS is a significant reduction in footprint, the weight and volume of ASLs that must be deployed to provide Class IX sustainment for supported units. This has several positive impacts, including reducing both deployment lift needs for supporting units and theater closure times for the deploying force during the initial phase of an operation, as well as improving sustainment during follow-on phases.

Over the past decade, the original military-focused, theoretical inventory management models developed and refined in academia (e.g., Wharton, Stanford) and the federally funded research and development centers (FFRDCs) such as RAND and the LMI have since spun off into

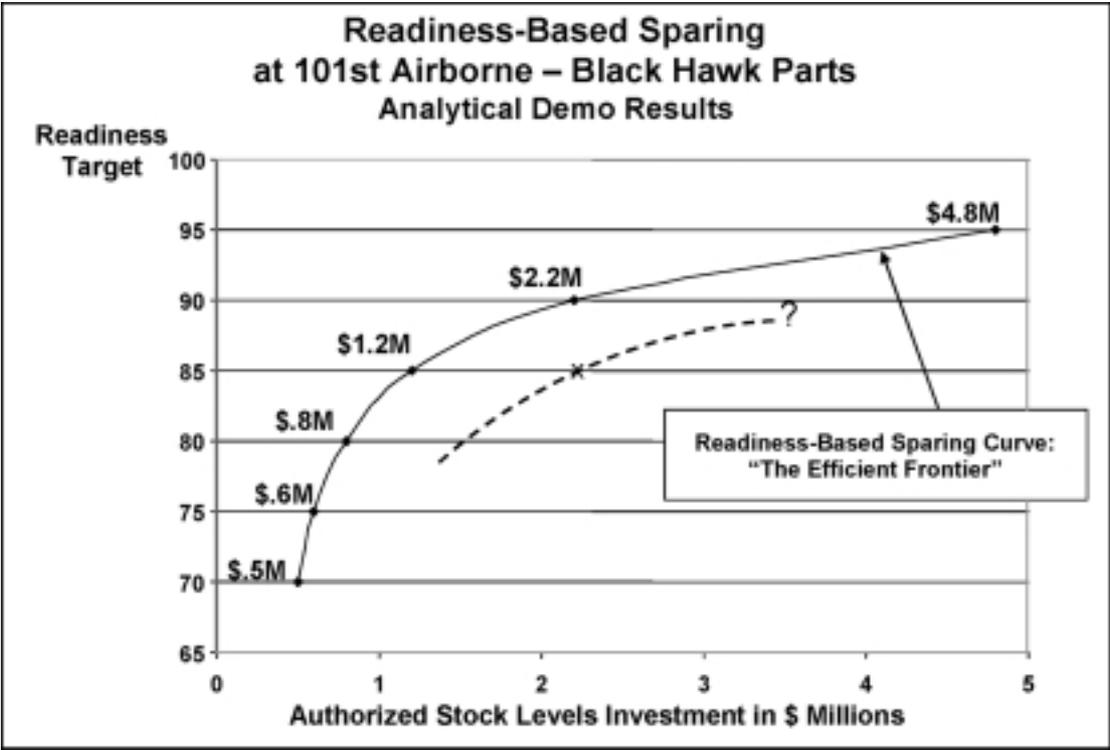


Figure 10

commercial firms. Several commercial off-the-shelf applications now fully capitalize on the use of STA/RBS algorithms and are applying them increasingly to support the proliferation of PBL contracts in the military, other government agencies and corporate customers such as commercial airlines and global service support providers (e.g., Caterpillar). These commercial applications have been successfully applied to complex supply chains—some in conjunction with ERP implementations—and are now competing in a growing market. The current focus is on accelerating computer processing times through heuristics and so-called “greedy algorithms” to achieve approximate solutions. For example, the Navy recently conducted an FFRDC-hosted RBS Olympics, inviting several commercial firms to demonstrate their respective capabilities to adapt and apply their software and algorithms to Navy-unique supply chains.

A second major effort is the incorporation of risk-pooling, or centralized stocking, to realize the benefits of reduced costs and improved supply performance through inventory pooling, especially for high-value but relatively low-demand DLRs. This potential was recently demonstrated with M1 Abrams tank engines for III Corps armor and mechanized units dispersed across five states near Fort Hood, Texas.<sup>40</sup> By transitioning from a hierarchical, arborescent logistics design (tree-like branching structure with serial, vertical supply channels) to a supply network incorporating responsive lateral supply links—especially for the many forward-positioned locations within the retail stage—risk-pooling coupled with improved asset visibility will enable the eventual attainment of a much more efficient, responsive and resilient demand-driven supply network (DDSN).

RBS should be expeditiously implemented as retail stock policy. Then, further enabled by risk-pooling (for low-demand but expensive spares), responsive lateral supply between ASLs and SSAs, and mission-oriented demand forecasting described in the previous section, Army inventory management policy could then transition from an archaic rule- and mandate-based support concept, which is neither mission- nor readiness-based, to a more flexible DDSN to be discussed in greater detail in the section “Multistage Integration for Efficiency, Resilience and Effectiveness.” Major benefits of such a policy include the ability to better anticipate the likely Class IX mission demand, then react and adjust more responsively according to the changing operational environment. Within the retail (forward-located) theater distribution system, the key enablers to achieving DDSN for a capabilities-based force are operational mission-based, empirically derived demand forecasts and RBS.

### **Retrograde/Reverse Logistics Stage**

The reverse logistics stage, or retrograde supply pipeline, constitutes the Army’s value recovery process for reparable spares and includes nearly 80 percent of the value requisitioned at the unit stage. From theoretical perspectives, both system dynamics and control theory suggest the responsiveness of this retrograde stage should have considerable impact upon readiness, the output of the system: it is clearly a feedback loop in the supply chain (figure 3 on page 6).<sup>41</sup> For these reparable items, the cycle created by the sequence of unit stage, then retrograde stage, then wholesale (depot repair) stage, then retail stage and back again to the unit stage forms a closed-loop supply chain. DLRs needing repair are turned in for retrograde by the unit, repaired by the maintenance depot, then returned through the forward supply chain back to the unit for

reuse to continuously generate readiness. Operating within the larger logistics structure, this closed-loop chain creates an internal dynamic system that can be altered through feedback to regulate the output variable of interest, which is readiness. However, opportunities for more cost-effective supply chain operations using a synchronized, closed-loop DLR processing cycle have not yet been fully appreciated.<sup>42</sup>

From a practical logistics network perspective, the more DLRs that are delayed in the reverse pipeline awaiting evacuation for repair, the more inefficient and unresponsive the reverse pipeline becomes, increasing the overall RO for those DLRs. For every DLR in retrograde, another similar, serviceable DLR is needed somewhere in the forward supply pipeline thereby increasing systemwide RO for that DLR. Or, if the DLR is not available, then customer wait time for a back order increases and impacts readiness at the unit.<sup>43</sup> Although not well recognized yet, this is characteristic of a tightly coupled system that can have potentially disastrous results without warning. An operational environment inducing greater stress on weapon systems may, for some parts, cause higher failure rates than normal. In the case of obsolescent DLRs that can no longer be quickly procured or repaired through commercial supply sources, they must be retrograded to AMC-level depots for repair, then returned for serviceable issue again through the forward supply chain. The responsiveness of the reverse pipeline then becomes crucial to support sustained operations when such higher-than-expected failure rates occur, resulting in temporary spikes or sustained surges in demand. This situation occurred during OIF, for example, in the case of wave guides for deployed Patriot Missile Systems. Near-heroic intervention, necessary to compensate for lack of visibility into an unresponsive retrograde process, was required to avert an extremely dangerous, acute situation that could have otherwise resulted in disaster.<sup>44</sup>

Despite these theoretical and practical implications, Army logistics regulations, processes and culture historically have not fully recognized the importance of this portion of the logistics network. The traditional Army supply system has placed little emphasis upon expediting or prioritizing DLR returns. For example, logisticians had no way to differentiate between types of return transportation used—surface or air—or the priority of a returning item. So Patriot Missile System wave guides, M1 Abrams tank engines and broken musical instruments all have, by default, the same lack of visibility and priority in retrograde even though their respective contributions to battlefield outcomes are dramatically different. Furthermore, since return in-transit visibility did not previously exist, unserviceable DLR returns could not be anticipated and repair depots could not accurately forecast workload. A final retrograde challenge, which significantly impacts the financial system, has been a disparity in DLR returns and issues to tactical units. Prior to OIF, the trend had been more issues than returns; but that has now reversed with more returns coming from OIF than issues. Recent data analysis indicates that the ratio of issues-to-returns across deployed units is highly variable, ranging between 40 percent and almost 100 percent. Furthermore, less than 20 percent of unserviceable DLR returns from deployed units currently can be traced to a final disposition.<sup>45</sup>

LOGSA is beginning to focus on identifying, measuring and quantifying delay times for DLRs awaiting retrograde in the reverse pipeline. These total retrograde time (TRT) values vary considerably across the overseas theaters, but are generally measured in months, not days

or weeks. Additionally, return times to various sources of repair (e.g., OEMs and depots) have been extremely variable, ranging from a few hundred to several thousand per month.<sup>46</sup> Efforts are now under way to create and capture reverse logistics (RL) data, measure TRTs for the various theaters, and estimate the value of reparables delayed in the RL pipeline. However, no study has focused on defining and quantifying both the potential reduction in aggregate DLR inventory requirements (RO) *and* the effects of reduced DLR CWT on improved readiness that could be achieved by synchronizing RL flow and depot operations with the forward supply chain. For example, U.S. Transportation Command (TRANSCOM), the new DoD “Distribution Process Owner,” recently announced improved retrograde operations. But the metric used was exclusively oriented on transportation cost reduction by shipping greater retrograde quantities by surface means (98 percent now) rather than more expensive air transport.<sup>47</sup> However, the “value” of the reverse logistics stage is not found in estimating the total price of DLRs delayed within it or minimizing reverse pipeline transportation costs, but rather DLR’s contribution to readiness, through cost-effective and responsive value recovery (figure 3, page 6).<sup>48</sup>

Once these various DLR network links and flows—including reverse pipeline flow, depot production, scheduling operations and forward supply chain flow—are connected and made visible through in-transit visibility (ITV), the Army’s enormous investment in DLR assets can be reduced. Plus, through better management within a synchronized, closed-loop supply chain, readiness will improve. Those assets that would no longer be required due to reductions in overall RO could then be used to create a variety of mission support packages comparable to Cold War prepositioned war reserves. These mission support packages would augment DDSN and better support a capabilities-based force. This would be especially valuable for aviation DLRs, which have limited war reserve stock but instead rely upon enhanced depot repair capacity to meet higher repair and replacement demand rates. A case in point is the recent experience for the T700 engine that has achieved an RO reduction estimated at nearly \$70 million as a result of reduced depot repair cycle time.

### **Wholesale/Depot Stage**

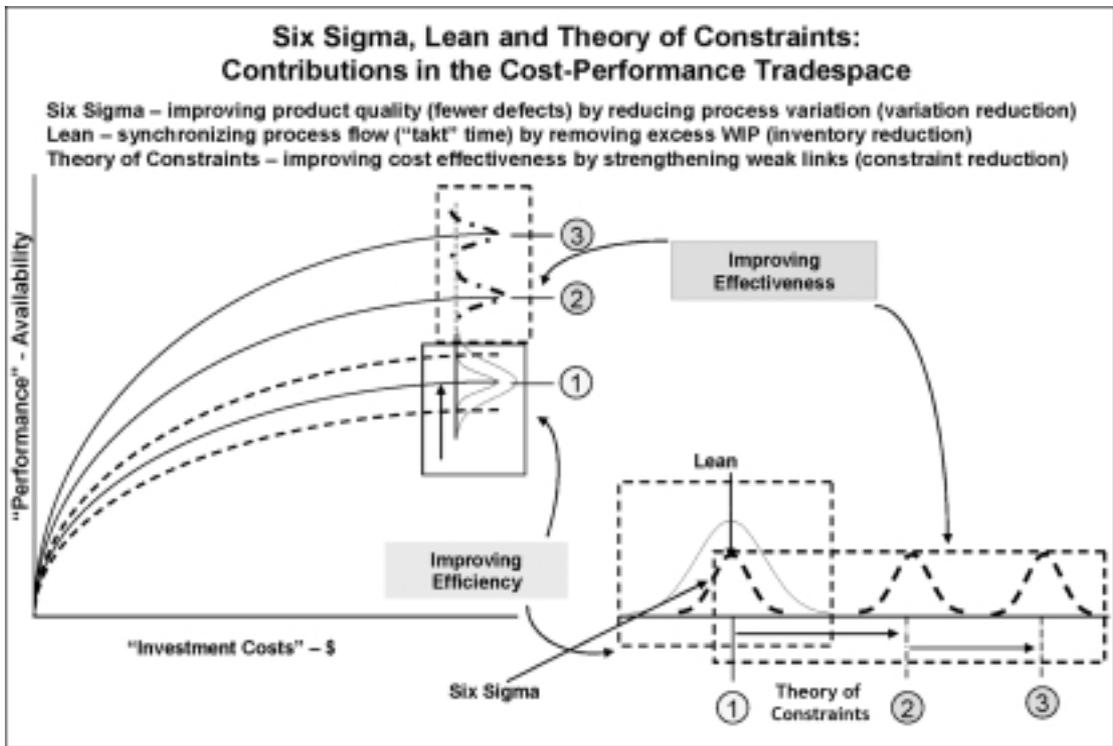
For Army Class IX spares, the wholesale stage incorporates two major functions. First, maintenance depots repair and rebuild end items (major weapon system platforms) and their major assemblies or subassemblies (engines, transmissions, blades, etc.). These components and end items, arriving through the RL pipeline at the depot for rebuild or modification upgrades, are considered reusable capital assets rather than consumable parts or items; hence the term “depot-level repairable.” These various repair depots belong to AMC’s subordinate commodity commands. Second, the national inventory control points (NICPs) control distribution for consumables, many of which are items and parts common to multiple services, and are managed by the DLA.

As mentioned previously in the reverse logistics stage, in-transit visibility for DLRs in the reverse pipeline has not existed until recently. Consequently, depots could not accurately anticipate the quantity, quality or timing of returns for repair to manage depot workload and synchronize returns of serviceable DLRs back into the forward supply chain. This lack of visibility and useful information further magnifies uncertainty and variability—the “bullwhip effect”—for DLRs,

which are also the most expensive spares, further driving up the aggregate systemwide requirement objective. Turnaround times (TAT) for repairs are further affected by obsolescence, diminished manufacturing sources of material supplies and, especially, depot parts stock that historically has been managed to a standard Armywide 85 percent wholesale supply availability target.

Recently, AMC incorporated Lean and Six Sigma manufacturing concepts into depot management practices with measurable success in reducing process variances and rebuild times. One clear example at the Corpus Christi Army Depot (CCAD) has been the success of the T700 engine line. A manufacturing concept originally pioneered, developed and refined by Toyota in Japan, Lean synchronizes process flow to reduce work-in-progress (stagnant inventory) and waste leading to a just-in-time approach to meet the pull of customer demand. In contrast, Six Sigma focuses on reducing defects to improve product quality by reducing variation, the proximate cause of product defects within the manufacturing process. However, significant additional improvements can now be obtained by adopting synchronized manufacturing—also known as optimized production technology from the “theory of constraints” (TOC)—for depot repair management.

TOC enables realization of significant effectiveness gains, as opposed to efficiency gains, within a truly synchronized closed-loop supply chain for DLRs (figure 11). Unlike Six Sigma, which uses statistical methods to uncover flaws in the execution of an existing process without actually challenging the process itself, TOC views the process as potentially flawed, an approach



**Figure 11**

generally referred to as identifying weak links in the chain. Increasingly, those companies following their Lean/Six Sigma efforts with this process redesign approach are finding “more success redesigning whole processes,” improving weak links and reducing or eliminating constraints to improve cost effectiveness and productivity.<sup>49</sup> An example of such dramatic improvement using TOC within the military depot system is the U.S. Marine Corps (USMC) Maintenance Facility in Albany, Georgia, where costs, work in progress and repair cycle times have been reduced, resulting in increased throughput and improved scheduling. For the MK-48 engines, the depot’s averages and variances for both repair cycle time and labor hours per engine have been cut in half, and engine output per month has more than quadrupled.<sup>50</sup>

Depot maintenance activities historically have experienced delays in obtaining consumable parts for repair and overhaul. This is partly due to the 85 percent target used by the wholesale system for supply availability. It also is, increasingly, attributed to obsolescence issues, especially wiring, avionics, corrosion and dynamic component degradation caused by aging aircraft and subassemblies. However, as retrograde efficiency and responsiveness improve, the combination of near real-time ITV and emerging on-board diagnostic and prognostic systems can provide anticipatory, feed-forward information for depot repair before the component actually arrives through the reverse pipeline. Hence, particular or unusual parts can be ordered before components and end items arrive for repair induction rather than after, further reducing depot repair TAT and aggregate systemwide reduced RO.

A recently completed Navy initiative, the Intelligent Collaborative Aging Aircraft Parts Support (ICAAPS) project, explored the value of such an anticipatory ability, illuminating the potential for reducing these forecasting lag effects, especially on consumable parts needed in maintenance repair. Because current projections for depot-level consumable part requirements are based on historical data, a considerable delay exists between actual need, particularly for aging aircraft, and when these same parts are incorporated into future requirement projections. The ICAAPS project successfully established correlations and relationships between depot-level discrepancies and consumable parts usage, as well as operating environments and field maintenance activities that could be expected to affect future depot-level maintenance requirements. The power to more accurately anticipate parts usage requirements and ensure that necessary parts were available upon induction for repair rather than at some later time cut the growing gaps between baseline usage rates and actual usage by more than 50 percent for many consumable parts. Consequently, by expanding the maintenance planning horizon to include all relevant information gathered during the entire operating cycle *before the aircraft arrived at the depot for repair*, ICAAPS was able to significantly reduce forecasting lag, improve part requirement forecasting accuracy and reduce depot repair cycle time.<sup>51</sup>

One of the great challenges in better synchronizing depot repair operations is being able to see all of the potentially useful information in multiple, geographically dispersed locations that could contribute to better forecasting. No single, integrated knowledge base exists to combine aircraft on-board data, potentially relevant unit-level operational information and programmed depot maintenance (PDM) data. Recognition of this limitation recently led to a joint initiative between the U.S. Air Force (USAF) Oklahoma City Air Logistics Center, which overhauls KC-135 tankers, and the Department of Energy’s Pacific Northwest National Laboratory (PNNL).

Using visualization techniques originally developed by PNNL for the U.S. intelligence community, several disparate data types and sources are linked and transformed and then presented on large computer graphic displays. These multidimensional spatial mappings use complex visual patterns that humans can interpret more easily than standard graphics, data tables or text. Known as the Visualization of Logistics Data (VLD) project, the analysis of trends, patterns and relationships in a large maintenance knowledge base enables logistics managers to capitalize on and exploit the human brain's visual processing capabilities to rapidly perceive and absorb visual representations of large amounts of data in a manner not possible through listening or reading. This capability provides for a consistent and integrated picture of the health of the aircraft fleet, better parts forecasting and reduced depot repair time and enables more informed decisions for PDM workflow, scheduling and resource forecasting.<sup>52</sup> When combining the capabilities offered by both ICAAPS and VLD, the potential for improvement appears enormous. When used in conjunction with an improved reverse logistics stage, these capabilities could pave the way toward a truly synchronized retrograde process, enabling a responsive closed-loop supply chain with both RO *and* improved readiness.

To accommodate surge requirements for a theater warfighting scenario, the Army has established prepositioned stocks to support early demands for ammunition and other classes of supplies, including medical supplies, end items and spare parts. These stocks provide additional capacity until the industrial base can ramp up production to meet higher demand rates. No prepositioned stocks exist in the case of the additional demand for aviation DLRs, however. Instead, the additional depot repair capacity needed to support higher repair and return rates is provided through four Aviation Classification Repair Activity Depots (AVCRADs) operating under the Army National Guard's Aviation Depot Maintenance Roundout Unit (ADMUR). In peacetime, these units are regionally located within CONUS and operated by reserve component Soldiers to support National Guard aviation units within their respective regions. When activated to support an operational theater, an AVCRAD mobilizes for deployment attached to AMCOM to increase capacity needed for initial surge and sustained aviation repair requirements. By design, when deployed and operational in theater, the AVCRAD reduces retrograde requirements by providing repair in-theater capability for DLRs, thereby improving deployed aviation readiness.

In practice, however, several organizational challenges emerged in support of OEF and, subsequently, OIF. The AVCRADs already were operating at or near capacity in their peacetime roles supporting their regional National Guard aviation units and providing overload relief to CCAD. When requirements for weapon systems needing overhaul exceed depot repair capacity, this backlog is deferred to future years as "unexecutable deferred maintenance." By the end of FY 2002, more than 50 percent of Army aviation-related depot-level maintenance requirements had been deferred and therefore not funded. Additionally, in 2002 AMCOM was short \$1.4 billion for DLR repair that was already approved for *current*-year PDM. As a result, no additional DLR surge capacity was available either at CCAD or in the AVCRADs by late 2002.<sup>53</sup>

Consequently, despite the mobilization and ongoing rotations of the regional AVCRADs to Kuwait to support in-theater repair demand in Iraq, the gap in overall capacity relative to higher repair demand requirements is still growing. This is, of course, the opposite result of what the AVCRADs were designed to achieve, but the consequence of insufficient slack capacity to

accommodate surge requirements in the current organizational design. Resolving this challenge, reversing this trend and developing additional maintenance capacity is crucial due to the converging effects of three trends that are combining to dramatically increase aviation maintenance, repair and spare demand rates:

- the continuing stateside demand, especially for National Guard units, for Operation Noble Eagle;
- the continuing demand to support overseas global operations, including OEF and OIF; and
- the growing demand of continually aging aircraft fleets, which are near or within their original design wear-out regions, with average fleet ages now increasing at a ratio of one year per calendar year due to the lack or cancellation of modernization programs.

Two major programs will stress wholesale supply availability as well. The Recapitalization Program (Recap) affects several weapon systems across the Army, both ground and air, and is intended to compensate for extending life durations—the useful life—caused by the absence or cancellation of major acquisition programs to replace these aging systems. This is a service life extension program using upgrades and component replacement or rebuilding to delay the system's entry into wear-out status when growing sustainment and repair costs become prohibitively expensive. The second, more recent program, initiated as a consequence of three war years' worth of extreme wear and tear and higher consumption rates, is referred to as the "Reset" program. Reset, unlike Recap, is intended to return equipment and systems to normally accepted conditions of maintenance and repair to achieve intended equipment operational readiness. In many cases, Reset is needed to rapidly return equipment to a ready-to-fight condition for the next rotation back to operational theaters. The FY 2005 supplemental budget estimates a total of \$9.2 billion for Reset, Recap, in-theater sustainment, depot maintenance and battle loss/damage replacement. An additional requirement of \$7.5 billion is considered "unexecutable" because repair capacity does not exist to expend these funds within the FY 2005 supplemental timeframe.<sup>54</sup>

The consequence of these additional wholesale spare demands is to dramatically increase the aggregate overall RO for Class IX within the Army's supply planning system. In the case of aviation Class IX, as cited in figure 1 on page 4, this funding requirement had already been growing substantially even before OEF and OIF. Overall, the AMC RO in 2002 was estimated at just under \$11 billion and is now believed to be in excess of \$20 billion (the Army budget, for comparison, is now about \$100 billion). The various elements that contribute to this aggregate RO and their differential growth rates can be identified, measured and associated with each of the various "stages" in the Army's multistage logistics model. Additionally, "safety stock" must also be included in this aggregate RO computation. This buffers against various sources of uncertainty within the demand and unit stages and variability across the supply stages—the bullwhip effect—which historically have not been isolated, measured and quantified.

However, this wholesale safety stock cannot currently be related in any meaningful way to a readiness-oriented outcome. This is a consequence of both the existing lack of integration across the logistics stages (to be discussed in detail later) and also, as emphasized earlier in the retail stage, a persistent inability to relate downstream retail investment levels to readiness outcomes because RBS has not yet been adopted. Moreover, this inability is reflected in the

interface metric the Army has traditionally used to measure this protective buffer or safety level. The term “safety level” actually confounds two distinctly different inventory management metrics: one, “safety stock” which represents the inventory investment (budget) in protection and, two, “service level” which measures the degree of customer satisfaction in terms of a meaningful output metric (figure 4, page 8). By confounding metrics—safety stock and service level into safety level—the only means to improve customer satisfaction (Ao) is to increase wholesale safety level, although the actual effect on Ao is unknown.

Consequently, AMC should adopt both safety stock and a readiness-focused metric (e.g., “back orders”) as management objectives for wholesale operations rather than safety level. Measuring safety level and supply availability as wholesale management objectives (interface metrics), which is the current practice, does not permit assessments of improved logistics network efficiency. As with the case of fill rate in the retail stage discussed earlier, managing the supply system to these interface metrics precludes identifying meaningful and cost-effective initiatives, programs and policies within an investment-performance tradespace. Other actions, especially work-arounds at the unit level, have persistently compensated for poor wholesale supply performance and masked actual wholesale stage contributions to readiness.

Regarding the second major function performed by the wholesale stage—national supply inventory management—recent LMI research sponsored by DLA’s Aging Aircraft program has focused on consumable inventory characterized by highly irregular demand patterns. These encouraging results have significant implications for the Army’s wholesale system as well, especially for aviation fleets. Across all services, specific repair parts in this category are infrequently demanded yet must be stocked because they are essential to sustaining aerospace weapon system readiness and safety standards. Traditional DLA practice has classified demands into two basic categories:

- Parts garnering at least four requisitions with a total quantity of 12 during the previous year are stocked under replenishment policy requisition objectives governed by standard inventory management models; and
- Low, infrequently demanded parts that do not meet the above requisition threshold are ordered under a numeric stock objective (NSO) policy. Their sporadic demand makes for difficult decisions about when to buy these items and in what quantities. This NSO policy has failed to produce good results at reasonable costs for more than 30 years. DLA’s new business modernization ERP does not provide an improved capability, either. Nonetheless, as systems become more reliable and infrequent demand patterns increase due to reduced failure rates, these sporadic demand parts are expected to grow.

LMI’s studies for both DLA and the Federal Aviation Administration (FAA)—large organizations that manage huge inventories for repairing complex systems across vast distances—have shown that this new “peak ordering policy” reduces both delivery delay times and back orders for these particular consumable parts. Additionally, experimental results for a range of aircraft (C-5, E-3, E-2C, F/A-18 and AH-64) are proving that this new peak policy can substantially reduce both inventory levels and procurement workload shortly after implementation. These results are significant because DLA’s sporadic demand inventory is currently worth more than

\$1.6 billion with annual sales to the services of more than \$400 million. This peak ordering policy, which now enables DLA (and the Army, if adopted) to make three-way trade-offs between service levels, inventory investment and frequency of procurement actions, is estimated to reduce overall delay times by 50 percent, the number of procurement actions by 35 percent, and the value of the sporadic demand inventory by 15 percent.

By simulating the distribution of back orders for aviation units operating under this peak policy, LMI has been able to estimate the reduction in NMCS and Ao improvement for these sporadic demand parts. In the specific case of the Army's AH-64, experimental results show this new policy, relative to the current baseline NSO, reduced delay times by 25 percent and DLA procurement actions by 40 percent during the period 2001 to 2003, while improving both on-hand inventory and fill rates by 10 percent for these sporadic-demand items. After five years of development, experimentation and review, this new methodology is now considered mature to implement as DLA policy for aircraft parts.<sup>55</sup> LMI currently is working on assessing peak policy effects for both sea- and ground-based systems and examining the policy's applicability for sporadic-demand DLRs. The Army, following DLA's lead, should consider adopting this policy and also supporting LMI's current investigation into peak policy implications for DLRs.

In addition to adopting readiness-oriented metrics (including Ao and back-order rate) and managing the entire inventory system focusing on equipment readiness (ER) results rather than on traditional interface metrics, inventory should also be assessed for quality as well as contribution to readiness. Quality is typically captured in commercial supply chains with inventory turns. Military spares inventories are more complex, however. For example, DLRs such as transmissions and engines are multi-item and multi-indenture as well as multiechelon, and also have obsolescence and aging challenges associated with long life cycles. Hence, a possible new but simple metric that may be considered as a means of capturing inventory quality is  $1 - [\text{excess inventory} + \text{obsolete inventory}]$ .

## Acquisition Stage

*Without a significant effort to increase resources devoted to recapitalization of weapon systems, the force structure will not only continue to age but, perhaps more significantly, become operationally and technologically obsolete.*

QDR Report 2001<sup>56</sup>

The acquisition stage in our graphical, multistage supply chain model (figure 3, page 6) represents OEMs and their supporting multitiered labyrinth of more than 100,000 suppliers for DoD. Collectively, they constitute the manufacturing capacity within the larger defense industrial base that responds to the procurement and sustainment needs of the Army. Though furthest removed from the readiness production function stage, this acquisition stage impacts supply chain responsiveness and, ultimately, readiness in two major ways:

- relatively short-term operational availability of spare parts, components (line replaceable units or LRUs) and end items that can have a direct, immediate impact on readiness at the unit stage; and

- longer-term operations and maintenance (O&M) support costs contributing to life cycle costs (LCC) over the extended duration of system use, typically several decades after research, development, test and evaluation (RDT&E), procurement and initial fielding.

The aviation supply chain's acquisition stage is fragile, vulnerable to price and lead-time escalation. It includes an increasingly higher proportion of sole-source suppliers which, in many cases, are sole sources to several different military and commercial OEMs. The Army seems to have little visibility into its second- and third-tier vendor base, which may be another root cause of supply lead time and stock availability problems. As a result of this lack of visibility, and with lead times of 300 to more than 500 days for many critical components, the only solution is high inventory at the wholesale level, again contributing further to the bullwhip effect. However, many of the high-strength alloy metals and aerospace steels used in helicopter turbine engines and transmissions are in tight supply and subject to dramatic price increases. Price and supply are cyclical and volatile, varying more than other industrial sectors. This volatility is partly due to the combination of limited original sources for strategic materials used in these alloys and steels, and partly due to the aerospace industry, which itself is vulnerable to cyclical market dynamics, representing about 70 percent of global demand for these materials.<sup>57</sup>

These aerospace supply chain dynamics are not new and have been studied extensively by commercial airplane manufacturers, who account for 40 percent of this demand. Boeing, for example, monitors these strategic materiel price fluctuations and cyclical relationships and their impact upon aircraft manufacturing capacity. Using system dynamics and discrete-event simulation to better understand cause-effect relationships, they have modeled their supply chain to quantify the impact of better-positioned inventory, improved collaboration and coordination, and reduced inherent delays within their supplier base. These dampening effects provide a more stable, cost-effective source of acquisition supply.<sup>58</sup>

It is not surprising, then, that a recent, ongoing study by the University of Alabama-Huntsville (UAH) for the Army's Cargo Helicopter (CH-47) Program Manager's (PM) office has encountered these same cyclical effects within the Army's aviation acquisition stage. Lead times are ranging from eight to 13 months for transmission gears and eight to 12 months for bearings—all from sole-source suppliers, many of whom are sole source to other Army helicopter program offices, too, as well as to the commercial sector. Market prices for materials needed to create the special alloys and steels used for these components have grown exponentially over this past fiscal year.<sup>59</sup> These conditions are occurring at a time when the acquisition stage already is overwhelmed with growing demand to support Recap and Reset requirements generated from an Army at war. This is another example, as was the Patriot wave guide retrograde issue described in earlier, in which the interactions between an unresponsive retrograde stage, a disconnected wholesale depot repair stage and an inefficient and unaware acquisition stage can directly and immediately affect readiness at the unit stage, potentially constraining the readiness needed to achieve demand stage requirements for operational missions. This is an increasingly dangerous situation confronting Army aviation logistics readiness, and it appears to be widespread.

This is not the first time the U.S. military has confronted these particular supply chain challenges.<sup>60</sup> One of the strategic materials used in aerospace steel recently afflicted by rapidly growing market price is cobalt, which has a limited source of supply mined in central Africa.

Around 1980 F-16 turbine engine blades were in high demand for production by the OEM. At the same time, not only were cobalt prices increasing but supply access was completely disrupted by rebels who controlled a crucial railroad in Zaire. Because the impact on readiness could not be tolerated given Cold War tensions at the time, the Air Force flew C-141s into central Africa in an effort to reconnect the supply chain by hauling cobalt back to the United States for commercial OEMs.

For professionals who have experienced and understand the consequences of these dynamics, the current perception is that these cyclical trends in the military are getting worse. This is largely a consequence of the contraction and consolidation of the defense industrial base in the post-Cold War era. Fewer suppliers are now facing greater demands from multiple customers. Potential solutions include the use of long-term, performance-based logistics (PBL) type contracts, which have built-in product surge capacity provisions. Examples of such contracts include the Army's M1 tank and the 30mm + an incentive to adopt supply chain management concepts to achieve readiness requirements specified by the contract, but must do so profitably. This is surely one reason why commercial STA/RBS providers, especially those with feasible multiechelon, multi-item, multi-indenture software capabilities, are beginning to flourish in partnerships with OEMs and service program managers, especially for complex military aircraft.<sup>62</sup>

The second, longer-term impact of the acquisition stage is on life cycle costs, primarily those associated with growing O&M support costs as a consequence of aging aircraft fleets coupled with the lack of modernization programs, which historically have constituted weapon system recapitalization. The primary focus of this paper, so far, has been on improving logistics performance using supply chain and inventory management concepts to derive efficiencies and improve readiness. This emphasis, using figure 8 (page 13) as a guide, has been on reducing MLDT. Obviously, other design factors also affect the operational readiness production function, notably maintainability (mean time to repair, or MTTR) and reliability (mean time between failures or MTBF). Maintainability and reliability are complementary aspects of aircraft availability and mission-generation capacity: reliability keeps an aircraft operational while maintainability enables an aircraft to undergo rapid repair and return to operational status when a failure occurs.

The implications of both MTTR and MTBF on O&M sustainment costs, although recognized from a theoretical design perspective, are now becoming operationally significant and increasingly expensive due to the unprecedented length of service for aging fleets. Previously, this had not been a major concern due to the normal 20- to 25-year acquisition cycle for modernization programs. Two issues are briefly highlighted here: one, the previous failure to credibly incorporate reliability and maintainability design considerations into total system life cycle costs, which are now severely impacting today's downstream O&M costs; and, two, the failure to recognize and correct for deviations between original design MTBF parameters and subsequent actual MTBF (or MTBR) empirical evidence derived from operational experience.

Regarding the first issue, "reliability design to readiness," significant work undertaken by the Institute for Defense Analyses (IDA) focusing on U.S. Air Force and U.S. Navy/U.S. Marine Corps fixed-wing aircraft, suggests that relationships among these design factors (MTBF and MTTR), operational availability goals and life cycle costs can be quantified. Furthermore, despite the lack of standardized cost estimating relationships (CERs) for reliability improvement, analysis and modeling using actual aircraft data revealed that increasing investment in reliability and

maintainability can significantly improve availability and reduction in life cycle costs. Traditional maintainability concepts that improve availability have included line-replaceable modules, accurate fault isolation and detection, and commonality. Among recent emerging concepts are condition-based maintenance (CBM), which capitalizes on prognostics and health monitoring systems to detect potential failure modes and thereby anticipate and preclude failure from occurring in the first place. Three major potential benefits accrue from this increase in aircraft availability:

- Life cycle costs are reduced as a result of O&M savings;
- Procurement quantities can be decreased without sacrificing the number of effective aircraft; and
- For ground systems, land combat modeling and simulation results suggest that higher reliability and availability lead to improved loss-exchange ratios across a range of scenarios, according to a recent study for the Army by RAND's Arroyo Center.<sup>63</sup>

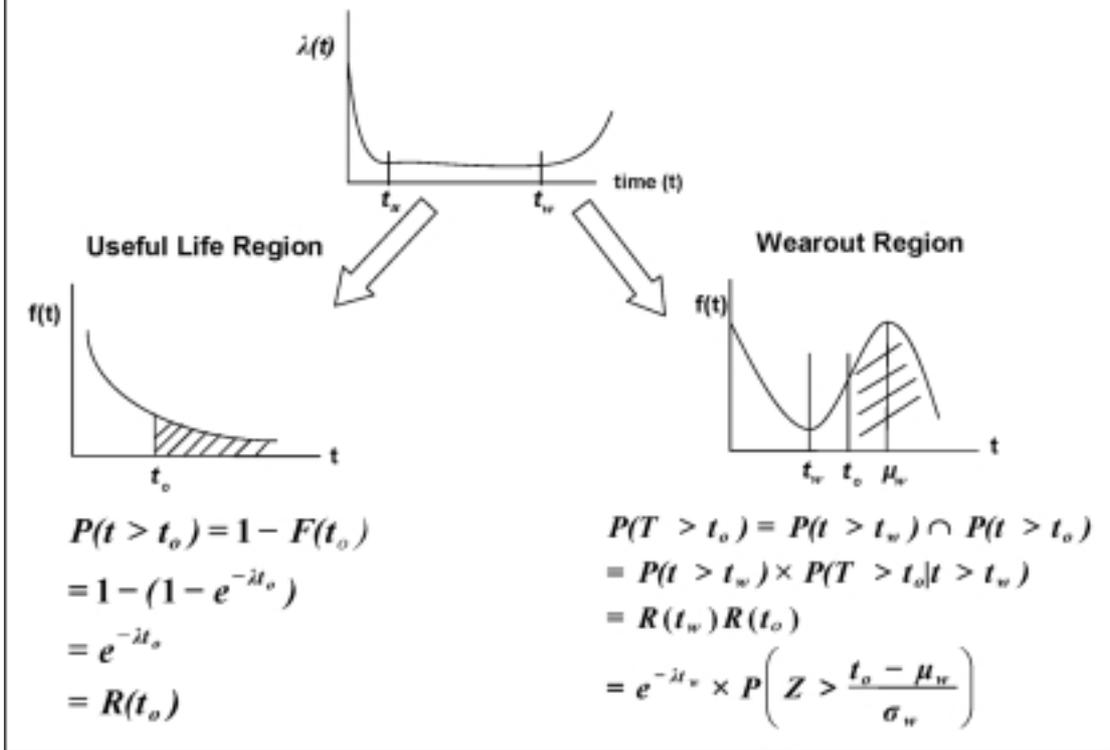
IDA's work also reveals that the more complex the aircraft the greater the potential savings from this reliability design to readiness cost benefit approach.<sup>64</sup>

Regarding the second issue—failing to correct and adjust for actual MTBF operational experience—recent work at the Naval Postgraduate School focusing on the F/A-18 emphasizes that “reliability is the single most dominant life cycle cost driver and is the key enabler of acceptable cost-effective operational availability.”<sup>65</sup> This particular case study, examining one of the aircraft's actuators, reveals the impact of failing to periodically review recent trends and recomputing spare support requirements in light of actual operational experience. Patterns of failure were found that exceeded provisioning stock levels by more than tenfold. Although experience clearly had shown that reliability declined over time, inventory support computations had not been updated nor requirements adjusted to accommodate those changes. This resulted in “under-budgeting logistic support, cannibalization and its costs, increased workload on maintenance personnel, potential safety risks and most significantly an operational readiness potential that was unrealized.”<sup>66</sup>

Without modernization, time and age will eventually degrade operational readiness and increase demand on repair resources as aircraft inevitably progress from useful life into the wear-out phase (figure 12). In the absence or delay of modernization programs, which is the situation now for Army manned rotorcraft systems, various service life extension programs (SLEPs) have been used to further extend useful life, particularly for major components. More recently, with entire fleets beginning to enter the wear-out phase, the Army has had to develop extensive, comprehensive Recap programs for 17 major weapon systems, including UH-60s, AH-64s and CH-47s. Given the extensive nature of Army Recap and the chronic need to mitigate the effects of aging, knowledge of rebuild and procurement costs, differential failure rate and remaining useful life patterns for various DLRs and subsystems should help program managers optimize their Recap programs.<sup>67</sup> In so doing they should heed the lessons learned from the two issues highlighted above:

- The goal should be to select for replacement/upgrade those DLRs and subsystems that minimize total program costs (including future O&M) subject to extending and achieving system availability goals; or

## System Life Cycle Failure Rate Pattern: The “Bathtub” Curve



**Figure 12**

- If faced with a fixed Recap budget, DLRs should be selected and prioritized to maximize their contributions to overall system availability.

Recap is, in essence, a reliability design-to-readiness program in which additional reliability is built into a platform within the useful life—or even wear-out phase, as with M1 tanks—instead of the traditional design phase of the system life cycle.

Recently, the Center for Systems Reliability at Sandia National Laboratories (SNL) demonstrated an impressive but, so far, underappreciated optimization methodology using the AH-64 Recap program as a demonstration. With genetic algorithms and artificial neural networks, the lab’s modeling and simulation methodology identified several specific DLRs and other cost availability drivers. Then, using current mean time between replacement data and marginal analysis (similar to the RBS methodology), it developed optimal solutions that identified a range of Recap investment costs with associated O&M savings. The analysis identified where additional Recap effort yielded diminishing marginal operations and support (O&S) savings. This powerful and insightful methodology demonstrated an ability to significantly reduce Recap costs by evaluating a wider range of potential DLRs to prioritize while also nearly tripling the availability improvement that had been projected for the baseline case. An additional benefit of this approach was realization

of a threshold beyond which Ao could not be increased regardless of the Recap investment level. This highlighted the importance of reviewing other potential sources of readiness improvement, including phase maintenance requirements and inventory management policy.<sup>68</sup> SNL's capability is portable, transparent and fast running, adaptable to other Recap programs and exhibits potential to evaluate future alternative prognostic and health monitoring concepts, as well. The various Army Recap programs should expeditiously adopt and implement its use. Savings generated can be used to further improve selected system Ao and support the growing demand for Reset programs, as well.

## Summary

Army logistics, particularly for aviation systems, suffers from several persistent disorders. These disorders, which are both systemic and chronic, have been illuminated throughout this section using inventory management theory, supply chain concepts and principles and logistics systems analysis as key sources of diagnostic power. To summarize, disorders and their respective effects include:

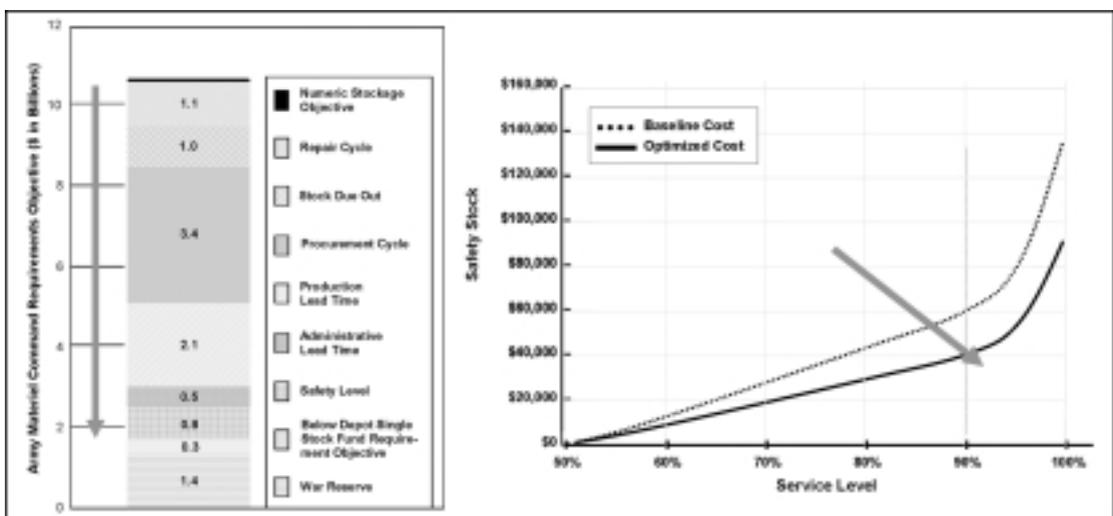
- lack of an aviation readiness production function, which induces both uncertainty and variability at the point of consumption in the supply chain, resulting in inappropriate planning, improper budgeting and inadequate management to achieve readiness objectives;
- limited understanding of mission-based, operational demands and associated spares consumption patterns, which contributes to poor operational and tactical support planning and cost-*ineffective* retail stock policy;
- failure to optimize retail stock policy to achieve cost-efficient readiness objectives, which results in inefficient procurement and reduced readiness;
- failure to proactively synchronize and manage reverse logistics, which contributes significantly to increased DLR RO, excess inventory, increased delay times and reduced readiness;
- inadequately organized depot repair operations that may be creating a growing gap in essential repair capacity while simultaneously precluding the enormous potential benefits of a synchronized, closed-loop supply chain for DLRs;
- limited visibility into and management control over disjointed and disconnected OEM and key supplier procurement programs that are vulnerable to boom-and-bust cycles with extremely long lead times, high price volatility for aerospace steels and alloys, increasing business risk to crucial, unique vendors in the industrial base resulting in diminishing manufacturing sources of materiel supplies, and growing obsolescence challenges for aging aircraft fleets;
- independently operating, uncoordinated and unsynchronized stages within the supply chain creating pernicious bullwhip effects, including large RO, long lead times and declining readiness;
- fragmented data processes and inappropriate supply chain measures of effectiveness (MOEs) focusing on interface metrics that mask the effects of efficient and effective alternatives

and further preclude an ability to determine readiness return on net assets or to relate resource investment levels to readiness outcomes;

- lack of central supply chain management and supporting analytical capacity results in multiagency, consensus-driven, bureaucratic solutions hindered by lack of an Army supply chain management science and an enabling analytical architecture to guide logistics transformation; and
- lack of an engine for innovation to sustain continual improvement for a learning organization.

The existing aviation logistics structure is, indeed, vulnerable to the bullwhip. While endless remedies have been adopted over the years to address apparent visible symptoms, the fundamental underlying disease has not been adequately diagnosed or treated, much less cured. The analytical challenge is to better understand and then attack the root causes that contribute to variability within each stage and volatility across the system of stages. By improving demand forecasting and reducing supply variability within each of the stages, logistics system performance is moving toward an efficient frontier in the cost-availability tradespace. The first step in suppressing the bullwhip effect is to isolate, detect and quantify the contribution these inefficiencies within each stage contribute to AMC systemwide aggregate inventory RO. Since Army inventories are managed to these computed ROs, reducing the value of the RO is a critical first step in eliminating unnecessary inventory.

As prescriptions for improved performance recommended throughout this section are implemented in each of the stages (see figure 3, page 6), their respective contributions to reducing RO while sustaining or actually improving readiness performance can be measured, compared and assessed in a rational cost-performance framework (figure 13). Then, for example, as retrograde operations become more responsive and contribute to a synchronized closed-loop supply chain, it becomes possible to reduce RO for specific DLRs by reducing both their back orders and associated safety stock *while increasing readiness*. The logistics system becomes



**Figure 13**

more efficient: RO (safety stock) is reduced while performance (back orders and Ao) is increased, thereby moving toward the efficient frontier in the spares investment-readiness performance tradespace (figure 2, page 5).

## **Multistage Approach—Integration for Efficiency, Resilience and Effectiveness**

### **Achieving an Efficient, Integrated Multiechelon Inventory Solution**

In addition to reducing demand uncertainty, identifying the causes and reducing the effects of supply and demand variability within each logistics stage, the stages must also be integrated and linked together to ultimately identify credible cause-and-effect relationships between Department of the Army resource allocation investment levels and readiness-oriented tactical outcomes. Although its recognition provides important insight into Army logistics, merely acknowledging that the aviation supply chain is vulnerable to the bullwhip does not automatically solve the problem. These effects can be avoided only if long-term organizational behavior and management processes are changed.

Another major AMC business function is the requirement to position and effectively manage a large, globally distributed inventory with millions of parts in hundreds of locations. The challenge is further magnified by these locations being situated in different tiers of the supply chain. One of the major difficulties in managing a multiechelon network is achieving an enterprisewide inventory optimization solution. Multiechelon inventory optimization is difficult for at least two reasons: replenishment policies are applied to a particular echelon without regard to the impact of that policy on other echelons, and higher-echelon (in this case, wholesale-level) replenishment decisions tend to be based on specious or unreliable demand forecasts. Failure to achieve an integrated solution results in several inefficiencies and degraded performance:

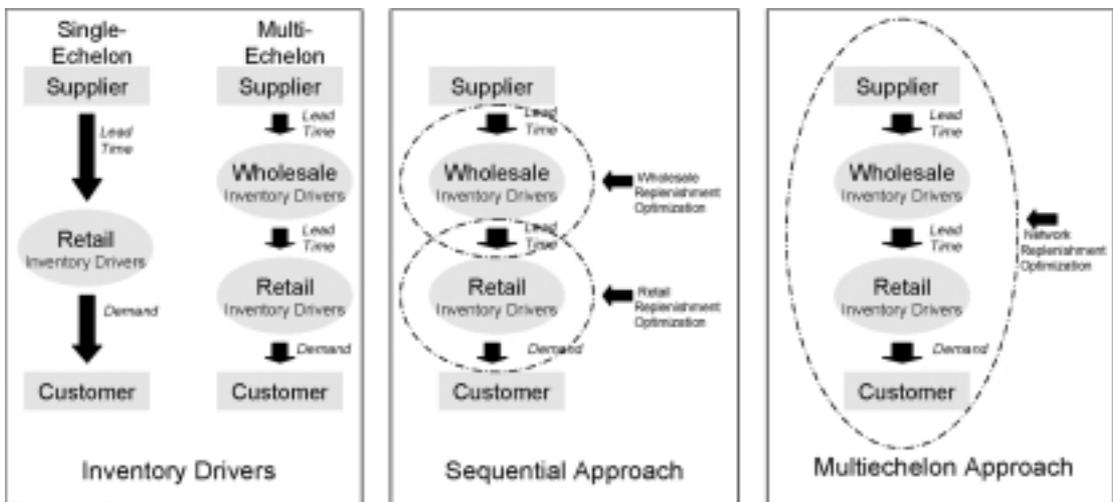
- The supply network carries excess inventory as redundant safety stock;
- Customers face shortages even when inventory exists elsewhere in the network;
- Shortfalls and back orders occur yet interface metrics between echelons (e.g., fill rates and safety level) appear to be acceptable;
- Upstream suppliers receive distorted and delayed demand projections and cannot deliver reliable performance; and
- Short-sighted internal allocation decisions are made for parts with limited availability.

Commercial enterprises characterized as multiechelon typically have used one of two approaches to address this inventory positioning challenge: one, a sequential application of the single-echelon approach; or, two, distribution requirements planning (DRP), an extension of materials requirements planning (MRP) used in manufacturing. Both approaches (figure 14), however, result in excessive inventory without necessarily improving performance levels. This occurs because an optimal solution for the entire network has not been achieved: total inventory has not been minimized subject to an outcome-oriented result such as customer service

performance objectives. Inefficiencies occur due to lack of visibility both up and down the supply chain: the retail stage has no visibility of the wholesale stage inventory balance, and wholesale lacks visibility into retail demand. Independent demand forecasts among the stages result in greater demand variation between them, leading to bloated but undifferentiated inventory levels, especially at wholesale. Furthermore, total network costs are difficult to assess, and the enterprisewide implications of new initiatives or strategies cannot be accurately evaluated because this sequential approach can only focus on their impact one stage at a time. Similarly, DRP, which uses a deterministic approach, cannot rigorously compute safety stock for the wholesale stage because retail stage demand variability has not been incorporated. As with the sequential approach, there is no link between safety stocks in the two stages.

In complex supply chains, a recurring management challenge is determining where and in what quantities to hold safety stock to protect against variability and ensure that target customer service levels are met. In an effort to improve supply chain efficiency, an appreciation for the interdependencies of the various stages is required to fully understand how inventory management decisions in one stage or location impact other stages throughout the supply chain. Consequently, an integrated, multiechelon network, if achievable, offers several opportunities for supply chain efficiency:

- Multiple, independent forecasts in each of the stages are avoided;
- Variability in both demand and lead time (supply) can be accounted for;
- The bullwhip effect can be observed, monitored and managed;
- Various root causes can be identified and their effects measured, corrected and tracked;
- Common visibility across the supply chain stages reduces uncertainty, improving demand forecasting and inventory requirements planning;
- Order cycles can be synchronized (this has special significance for DLRs in the retrograde and depot repair stages);



**Figure 14**

- Differentiated service levels (e.g., Ao targets for different units) can be accommodated; and
- Action can be taken to reduce unnecessary inventory and operational costs while simultaneously improving outcome-oriented performance.<sup>69</sup>

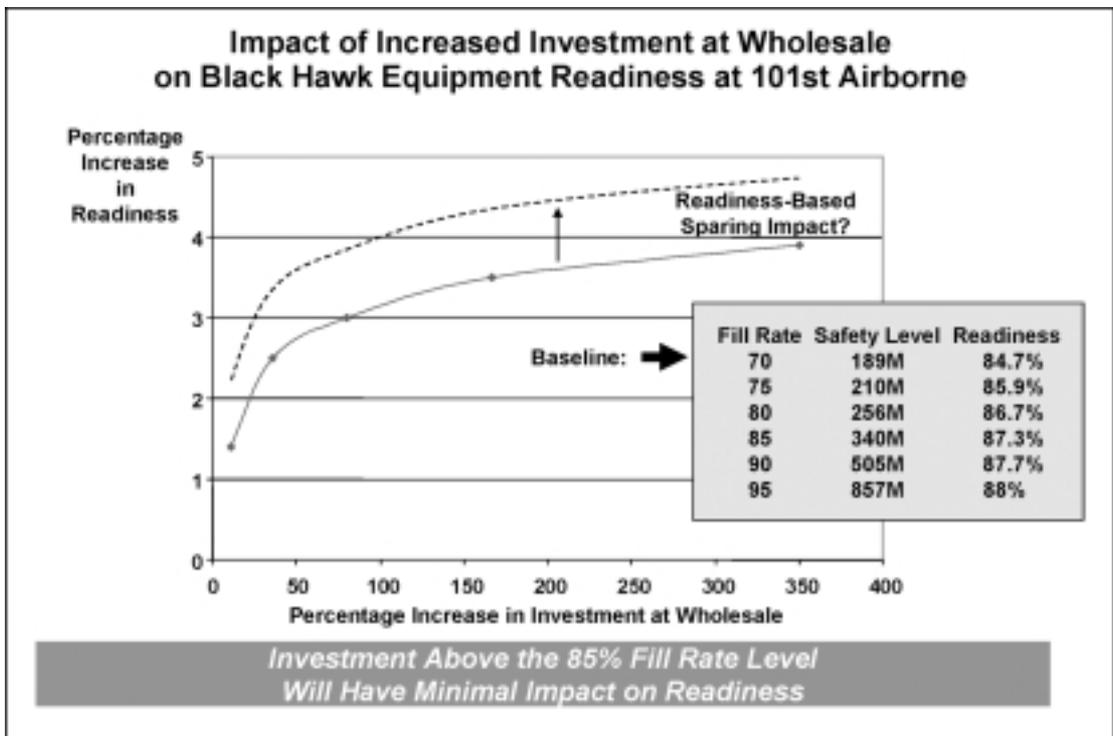
Efficient results are then possible and the organization can have greater confidence that it is operating on the efficient frontier within an investment-performance tradespace (see table below).

Key Areas	Sequential Approach	Distribution Requirements Planning Approach	True Multiechelon Approach
Optimization Objective	Meet immediate customers' retail or wholesale distribution center service goals at minimum inventory; suboptimal for network.	Not optimization; objective is to provide net requirements upstream to determine replenishment needs.	Meet end-customer service goals at minimum inventory.
Demand Forecasting	Independent forecasts in each echelon based on immediate customer's demands.	Pass up demands or projected orders with no measures of their variabilities.	Forecasts based on lowest echelon's primary demand signals and other information; demand variations also are forecasted.
Lead Times	Uses immediate suppliers' lead times and lead time variabilities.	Uses immediate suppliers' lead times; ignores variabilities.	Uses all lead times and lead time variations of upstream suppliers.
Bullwhip Effects	Ignored	Ignored	Effects measured and accounted for in overall replenishment strategy.
Network Visibility	Immediate downstream customers' demands and immediate upstream suppliers' lead times—myopic view of the network.	Some downstream visibility; no upstream visibility.	All echelons have complete visibility into other echelons; this visibility is exploited in the replenishment logic.
Order Synchronization Between Echelons	Ignored	Maybe, probably not	Fully modeled to reduce unnecessary lags in network.
Differentiated Customer Service	Not possible	Not possible	Achievable, as orders out of a higher echelon location to a lower echelon are fully controllable; allocation schemes using set-aside inventories can be used.
Cost Implications Between Echelons	Not possible	Not possible	Fully modeled so true network optimization can be achieved.

Within DoD and its supporting FFRDCs, the mathematical theory for multiechelon, multi-indenture, multi-item optimization supporting military inventory systems has been developed and refined over recent decades. Much of this pioneering theoretical work, primarily focusing on ground-based land combat systems, was accomplished by scientists and mathematicians at the Army Inventory Research Office (IRO) in Philadelphia, which was abolished in the early 1990s,

and much of the original talent at IRO retired or was reassigned. For military aircraft, experience has shown that DLRs most directly relate to aircraft performance and, in general, minimizing the sum of DLR back orders is equivalent to maximizing aircraft availability.<sup>70</sup> Significant effort has also been placed on determining optimal stock levels and locations for reparable components in a multiechelon system. While the subsequent extension of this theory has been widespread,<sup>71</sup> the focus of practical implementation within DoD has been on fixed-wing aircraft in the Navy and the Air Force rather than rotary-wing aircraft in the Army.

Another “structural constraint” which previously precluded an integrated multiechelon approach for Army supply systems was the Army financial management system’s use of separate stock funds for retail and wholesale operations. In recent years, these funds were combined into one revolving fund, the Single Stock Fund (SSF) within the Army Working Capital Fund (AWCF). In theory, this should both facilitate and encourage adoption of an integrated multiechelon approach. For example, at AMCOM, the wholesale stage now has both visibility into the retail stage and more control over stock policy in the wholesale *and* retail stages, which it previously did not have for aviation and missile Class IX. Upon achieving milestone III for the SSF program, AMC would be able to incorporate a multiechelon optimization model and enable wholesale stock levels in addition to retail RBS solutions, to be directly related to readiness (figure 15). However, in practice so far, although AMC owns these retail stocks under this new SSF program, ASL and SSA stocks are still being managed by retail organizations as in the past.



**Figure 15**

The key enabler for improved efficiency in all Army weapon system supply chains—and the more complex the system, the more crucial the enabler—is adopting multiechelon RBS. This is an essential precondition for meaningful logistics transformation in the Army.

### **Designing a Resilient, Adaptive Logistics Network**

*We cannot forget the lessons we have learned. Our wars have not been one size fits all, and neither have our logistics. We need to remain flexible in planning for future logistics. . . . [Now] in an age of network-centric warfare, we need to sense, anticipate, respond, and do logistics better.*

General Paul J. Kern<sup>72</sup>

The intent is certainly *not* to blindly adopt the corporate world’s latest management fad, but rather to consider adapting proven concepts to the unique needs and challenges the Army now faces. For example, the idea of integration, when achieved by reducing slack or waste in the system, does not necessarily enable greater flexibility. The opposite result could occur with just-in-time methods. Lean manufacturing concepts have certainly helped firms become more competitive through the application of just-in-time principles, which exchange industrial age mass for information age velocity. Furthermore, many of the original lean manufacturing concepts, especially the focus on reducing stagnant inventory within a company, have been successfully adapted for supply chain management (SCM) across the entire value chain, which includes the customer who is pulling value through the supply chain. Nonetheless, just-in-time manufacturing concepts, although a powerful inventory reduction method, need stable, predictable supply chains for maximum efficiency. Even when enabled by IT, lean supply chains can be fragile, vulnerable to disruption and unable to meet surge requirements for an immediate increase in demand. In fact, recent official documents describe exactly such a condition for Army logistics in recent years. Greater duress and the compounding stress of ongoing wars on the military logistics system has resulted in “a lean supply chain without the benefit of either an improved distribution system or an enhanced information system.”<sup>73</sup> A more appropriate analogy for Army logistics is a flexible, robust logistics network—not a serial chain or hierarchical arborescence, but rather a network spider web enabled by a strong analytical foundation with supporting information technology to achieve an integrated, flexible, efficient and effective logistics capability.

These adaptive network concepts are driven by an overarching DoD transformation program coordinated by the Office of the Secretary of Defense (OSD) Office of Force Transformation (OFT). For logistics, one of six major battlespace functional area groupings—others are fire, maneuver, protection, command, control and communications (C3) and information/surveillance/reconnaissance (ISR)—this visionary adaptive enterprise capability is referred to as “Sense-and-Respond Logistics” (S&RL).<sup>74</sup> The basic foundational theory for S&RL is derived from the autonomous nervous system in biological systems which, in conjunction with the sensory perceptions of sight, smell, taste, hearing and touch, enable reactive and anticipatory protective responses. This S&RL concept builds upon IBM’s autonomic computing initiative in which machines use on-board diagnostic sensors to assess and monitor system health, forecast and predict system and component level failure using prognostics, then employ automatic identification technologies to alert maintenance and logistics managers and engineers to problems before they

become visible. S&RL further extends this autonomic logistics platform-level concept to the larger logistics support network, thereby providing the capacity to predict, anticipate and coordinate logistics support wherever and whenever it is needed across the battlespace. Conceptual documents currently describe S&RL as a “network-centric, knowledge-driven, highly adaptive, self-synchronizing, dynamic and physical functional process [which] achieves ‘effects-based’ operations and provides a precise, highly agile, end-to-end, point-of-effect to source-of-support network of logistics resources and capabilities.”<sup>75</sup>

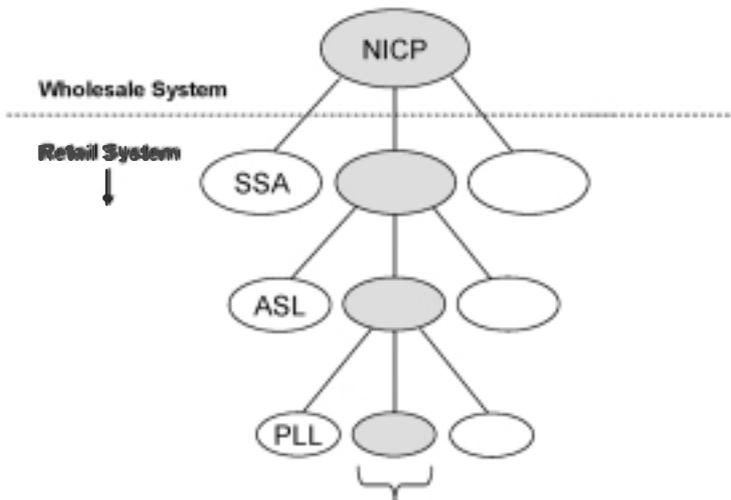
These adaptive network concepts have evolved from pioneering work performed at the Santa Fe Institute focused on understanding how immensely complicated networks, made up of large numbers of interacting agents that cooperate and compete, regularly arrange themselves into complex organizations that are efficient, adaptive and resilient though the various agents are pursuing their own interests. According to this complexity theory, efficient, self-organizing systems like this emerge only at the edge of chaos, somewhere between a prescribed rigid order that is unresponsive to new information (including threats) resulting in paralysis, and a system so overloaded with new information that it dissolves into chaos. These so-called “complex adaptive systems” become self-organizing by responding to external conditions while maintaining an internal integrity that keeps them together and cohesive. This results in a higher level of order that enables the system to adapt in ways that continually benefit its member agents. Accurately predicting the future for such a complex adaptive system is not possible. Therefore, the optimal solution cannot be engineered in advance. Research is showing that some of the greatest improvements occur when these self-organizing systems are forced to respond to random or unexpected events and thereby discover creative “solutions.”

This ambitious S&RL vision endeavors to replicate, albeit in a highly accelerated fashion, these evolutionary, nonlinear biological concepts rather than linear mechanical engineering systems that have been the traditional province of large-scale systems design. Nonetheless, our ability to actually implement these concepts, especially at the theater and tactical levels for Army and joint logistics distribution, may be much closer at hand now than was previously recognized. The DDSN—which includes operation-based forecasting on the demand side and RBS, lateral supply and risk-pooling (especially for DLRs) on the supply side—provides the foundational basis for such a versatile, adaptive, agile and resilient network web (figure 16). Through both theoretical development and recent field tests, this DDSN concept has also been shown to attain improved effectiveness (Ao) plus more efficiency as total asset visibility (TAV) and ITV IT-based technologies are incorporated.<sup>76</sup> Such a theater- and tactical-level DDSN is not only effective and efficient but also resilient and adaptive and will enable a rapid transition away from the traditional hierarchical arborescent structure toward an adaptive network design consistent with S&RL.

### **Improving Logistics Effectiveness: Pushing the Performance Envelope**

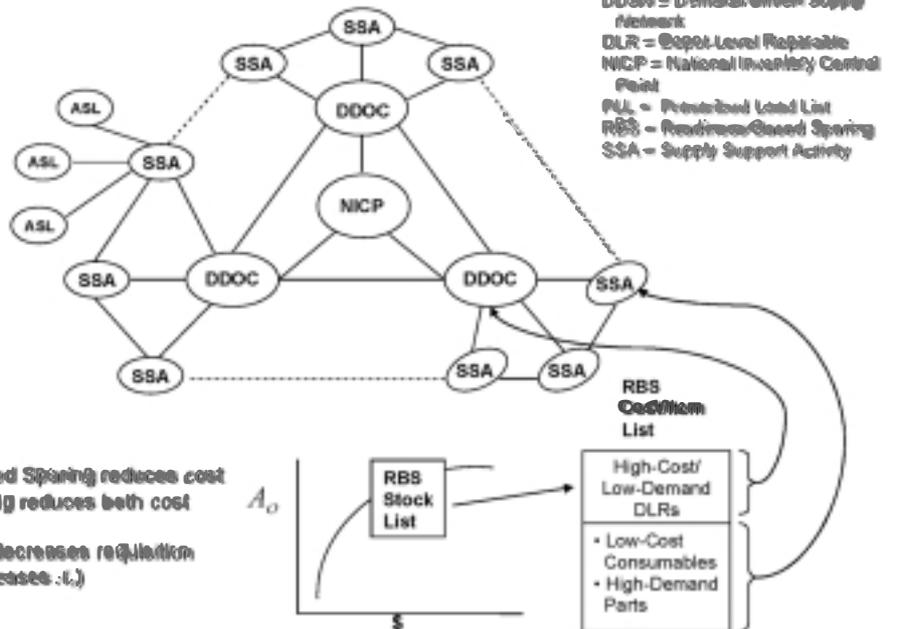
So far, using supply chain concepts and the graphical Army multistage logistics model (figure 3, page 6), this paper has isolated and identified several challenges and opportunities both within these several stages and across them. However, it has not explicitly differentiated between “efficient” and “effective” solutions within the investment-performance tradespace. This section

### Current Structure: Arborecence



- Vertical “serial chains” create vulnerable supply channels.
- Increased buffer stock is required to reduce risk but results in increased inventory investment costs.

### Demand-Driven Supply Network (DDSN)

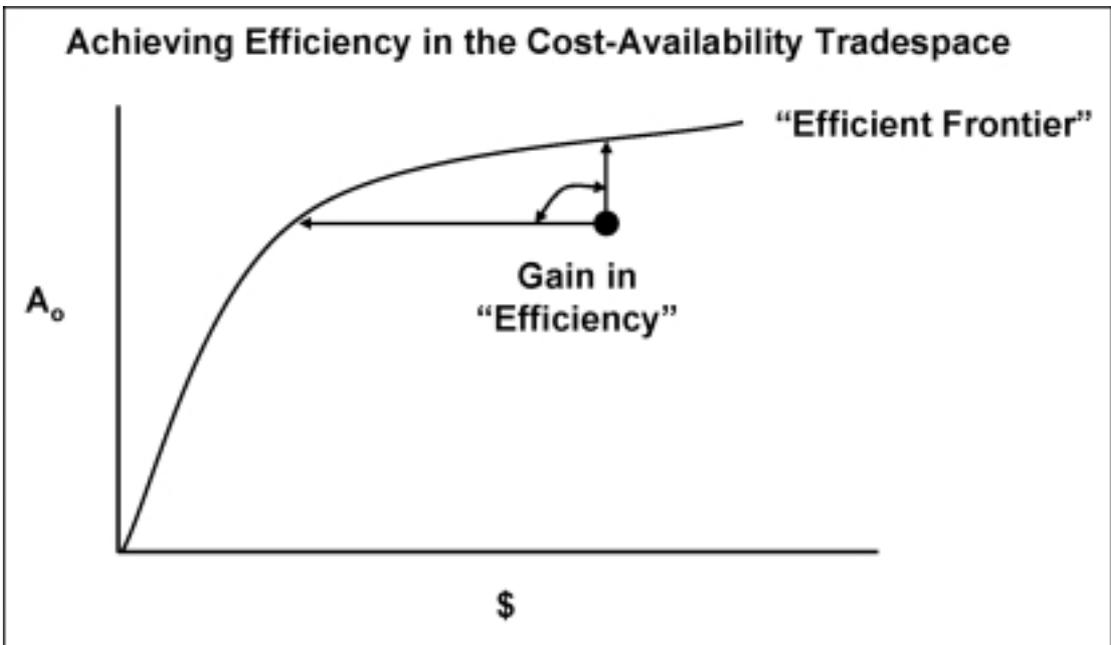


- Readiness-Based Sparing reduces cost
- Inventory Pooling reduces both cost and risk
- Lateral Supply decreases requisition delay time (increases  $A_o$ )

Figure 16

clarifies and illuminates these distinctions using the graphical tradespace construct that has been a consistent theme throughout the paper. Then, using additional analytical methods and concepts, this section further endeavors to develop and offer an analytical architecture to guide logistics transformation for the Army.

By “efficient” we refer to those methods (whether policies, techniques, procedures or technologies) which, if adopted, reduce uncertainty or variability within any particular stage as well as across the system of stages that comprise the multistage logistics enterprise. The results of these methods would have the effect of moving toward the efficient frontier in the cost-availability tradespace (figure 17). Achieving an efficient solution implies the best possible use of existing resources *within the constraints of the current system design and business practices*, and therefore results in operating on the existing efficient frontier.

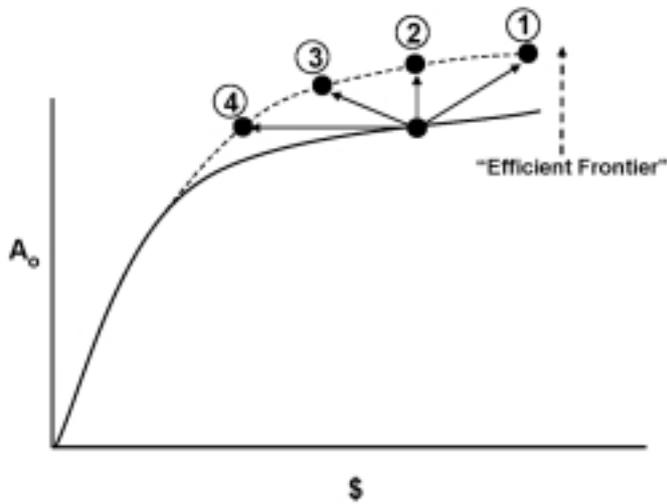


**Figure 17**

A more “effective” method is one that actually shifts the existing efficient frontier to a different “operating curve,” thus suggesting that current business practices are actually being changed. Cost-benefit analyses can be performed on various initiatives that yield improved but different results (figure 18). The relative magnitude of each of these cost-benefit alternatives, however, depends upon knowing the location on the current efficient frontier and the expansion trace of the new, improved frontier of an existing “efficient” operation that, through organizational redesign, business process changes or other forms of reengineering, becomes a more “effective” operation.

The obvious graphical goal is to sustain continual improvement and progress over time through innovation in all of its various forms (figure 19). This is the essence of productivity gain, and in

### Achieving Effectiveness in the Cost-Availability Tradespace



#### Cost Benefits Alternatives:

1. Improved effectiveness with increased costs
2. Improved effectiveness at same costs
3. Improved effectiveness at reduced costs
4. Same effectiveness at significantly reduced costs

... however, magnitude of each depends upon where you are on the *current* efficient frontier!  
... and the expansion trace of the improved frontier (i.e., "Pushing the Envelope")

Figure 18

### Pushing the Envelope: Innovation to Sustain Continual Improvement

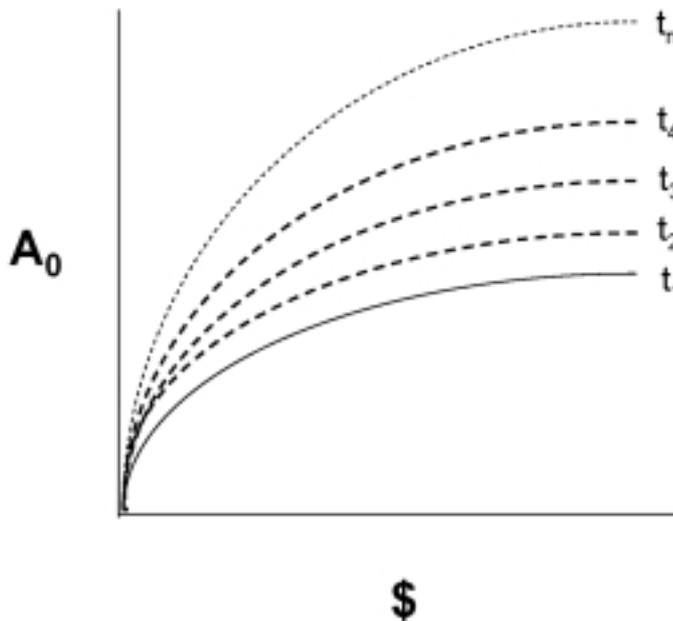


Figure 19

competitive markets it differentiates those commercial firms that successfully compete and flourish over extended periods from those that do not. A noncompetitive governmental activity needs an engine for innovation to compensate for the lack of competitive marketplace pressures typically driven by consumer demand and customer loyalty. The most obvious engine for a military organization is imminent or evident failure on the battlefield. Failure in battle, especially if sufficient to cause the loss of a major war, clearly constitutes an “unmet military challenge” that is one of several key historical prerequisites for a “revolution in military affairs” (RMA).<sup>77</sup> However, the U.S. military, especially the Army, has been extraordinarily successful in recent operations, despite several acknowledged logistics shortcomings. The current issue, then, is whether these real, persistent and serious logistics inadequacies are sufficiently compelling to warrant the necessary attention, resources, sustained intellectual support and extended commitment required for change. Indeed, a fundamental question is will, or even *can*, a so-called logistics transformation actually occur, especially with the nation at war? So far, however, the actual experience of more than a decade and a half of both Logistics Transformation and the Revolution in Military Logistics that preceded it offers a resounding “no” to this fundamental question. As a U.S. Army War College Strategic Studies Institute thesis states:

Every Army Chief of Staff, Chairman of the Joint Chiefs of Staff, and Secretary of Defense in the last 15 years has stated unequivocally that a true transformation of the U.S. Army cannot occur without significantly changing the way we conduct logistics. The premise is that logistics is clearly the one area that absolutely must be transformed if the Army’s vision of the future force is to be realized.<sup>78</sup>

As with many large commercial firms, the Army appears to be paralyzed by an innovation trap. The consistent pattern has been one of internal cognitive capacity denying the need for change, thus causing an inability within these organizations to commit to large-scale transformation efforts before it becomes too late.<sup>79</sup>

In the absence of imminent or evident failure resulting in battlefield losses that threaten the nation’s interests, an alternative engine for innovation is an extensive experimentation capacity providing an ability to see the impact of alternative concepts, policies, procedures, doctrine, tactics and organizational design—a virtual environment that can realistically illuminate a better way of doing things and thereby possibly preempt future failure. This experimentation capacity must also have a receptive organizational climate, including strong, sustained leadership support, mechanisms that actually enable discovery and learning to be derived from these experiments, and the institutional means to incorporate positive results into new or existing policies, doctrine and resource programs—in short, a bureaucratic capacity to both encourage and accommodate change. Several illustrative examples exist of successful engines for innovation within the Army that have had influential, positive results.

One example with relatively long-term, sustained effects is the transition toward simulation-based training to capitalize upon the emerging power of virtual and constructive simulation technologies. This opportunity was initially forced upon the Army by both increasingly prohibitive training costs and decreasing availability of adequate real estate for live maneuver training areas, largely a consequence of the environmental movement. The resulting revolution in training and training technology has been ongoing for more than two decades.

A less conspicuous example within a much shorter timeframe concerns the dramatic challenges to the Army's recruiting mission in the late 1990s. After nearly a decade of decline endstrength during the post-Cold War drawdown, the demand to stabilize Army numbers led to increasing recruiting requirements at a time when youth market conditions had become the most difficult and demanding in the history of the modern All-Volunteer Force (AVF). After several years of failed recruiting missions and retention challenges, Army combat organizations were struggling to meet personnel readiness objectives. Facing imminent failure and with the support of the Army's senior leadership, U.S. Army Recruiting Command (USAREC) successfully implemented an engine for innovation that directly addressed the fundamental nature of the challenge. This transformation engine included nationwide testing, experimentation, modeling, market and recruiter surveys, extensive simulation and rigorous analysis, all conducted by newly formed but cohesive, multidisciplinary teams of experienced recruiters, demographers, labor economists, statisticians, advertising experts, military psychologists and sociologists, market research and operations research analysts and systems engineers. Within a span of three years (1999–2001), USAREC suffered its worst recruiting year, completely "reengineered" itself while "transforming" its approach to the youth market, then enjoyed the best year in its 30-year history.<sup>80</sup>

These examples, though very different in form, duration and content, suggest the power, value and enormous contribution provided by a strong, comprehensive, analytically based engine for innovation as a surrogate for failure to motivate needed organizational transformation. Consensus-driven demonstrations, which the Army has adopted in recent years—replacing analytically sound, empirically based experiments and field testing for warfighting concept development—do not provide, and are not a substitute for, an adequate engine for innovation. The bad news is that an engine for innovation has not yet been adopted to support logistics transformation, much less accelerate it. The good news is that the U.S. Army, as these two examples illuminate, clearly has the experience and the potential capacity for doing so.

### **An Analytical Architecture to Guide Logistics Transformation**

Several agencies and organizations have logistics modeling and supply chain simulation capabilities that could be pulled together, just as the new Army aviation-focused logistics readiness project is now attempting to do.<sup>81</sup> They must now be integrated, even if loosely, into a more formal research consortium to better coordinate their efforts, reinforce their respective strengths and better facilitate properly sequenced field tests, experiments and evaluation with supporting modeling, simulation and analysis. When this is accomplished, these organizations could form the nucleus of an engine for innovation for logistics transformation. Several commercial and academic applications, concepts and sources of expertise could also be included.<sup>82</sup> Another possibility is to create, as the Navy is now doing, a dedicated organization consisting of a partnership with both academia (for creative, cutting-edge concepts) and the corporate world (for existing commercial applications) working in conjunction with a new, congressionally funded logistics readiness research center. A similar partnership recently proposed by UAH is the Center for Innovation in Logistics Systems (CILS).

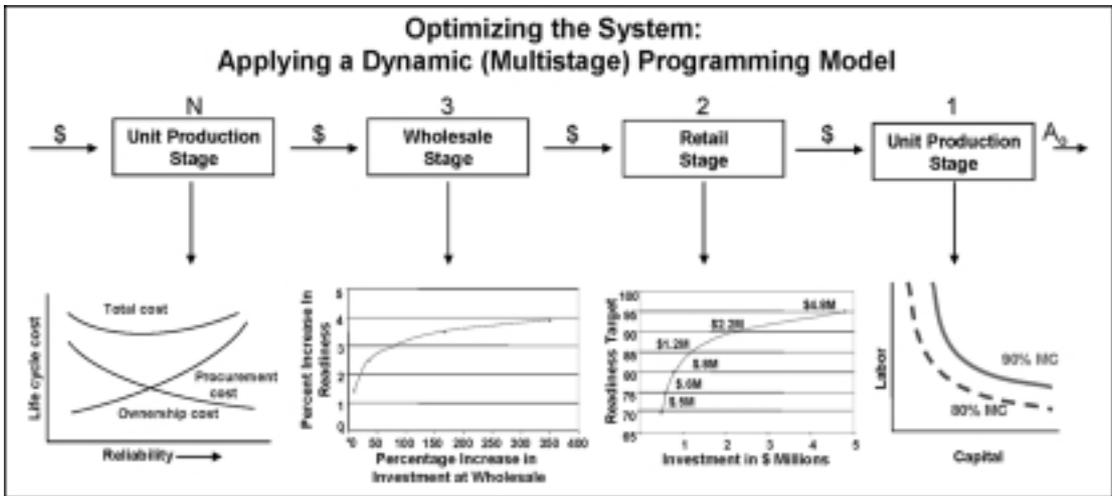
The purpose of this engine for innovation, regardless of the form it might take, is to provide the large-scale systems simulation, analysis and experimentation capacity and expertise needed

to serve as a credible test bed. This capability would generate the compelling analytical arguments needed to induce, organize, sequence and synchronize the many changes needed to accelerate transformation for Army logistics. Furthermore, it would offer potential for quantum improvement over the PowerPoint analysis that has become pervasive.

The modeling and simulation methodology outlined below, if implemented in conjunction with this engine for innovation, would constitute dynamic strategic planning for logistics transformation. The intent is to avoid the typical project management master plan approach, which prescribes a predefined, set of tasks with tightly specified milestone schedules. Dogmatically following such rigid master plans may be mandated by various DoD regulations and federal contract laws. Yet, these constraints discourage the possibilities of adjusting program initiatives and tasks when necessity requires or opportunities arise through adaptation and experimentation. A more responsive, adaptive planning approach is needed to accommodate doctrinal changes driven by evolving mission needs and operational concepts or to capitalize on emerging results from experimentation, field testing and unanticipated breakthroughs.

Operational conditions, emerging testing results or outcomes from previously enacted policy changes may illuminate a clear and compelling need for adjusting the plan at a point in time (most likely several times) by revealing certain project tasks that should be resequenced, accelerated or implemented in a more comprehensive manner. On the other hand, further testing and evaluation may be needed to resolve key anomalies or concerns, thus causing delays or completely eliminating initiatives that are not sufficiently mature for implementation or have been precluded by better methods. The generation of these options and resulting decisions should be grounded in thorough cost-benefit analyses conducted in a large-scale systems modeling environment for the Army's logistics system.<sup>83</sup> This logistics analysis test bed could be patterned after any one or combination of several organizational constructs, including the U.S. Army Training and Doctrine Command (TRADOC) battle lab or a center for innovation such as the proposed UAH Center for Innovation in Logistics mentioned above. The purpose, function and relationships of four key enabling analytical components of this approach are described in the following paragraphs.

First, the multistage conceptual model used above to analyze the Army's logistic structure naturally lends itself to the use of dynamic programming (DP) or a comparable problem-solving technique. DP is designed for complex, nonlinear, mixed discrete/continuous problems that can be decomposed into smaller, more manageable parts for analysis and then recombined to yield systemwide optimal solutions. The basic concept that makes DP relatively unique in the field of mathematical programming optimization theory is called the "principle of optimality." DP works backward through the several stages of the problem to ultimately derive an optimal solution using a solution procedure rather than the mathematical algorithm typical of other optimization methods.<sup>84</sup> Using figure 20 for reference, aligning four of the six logistics model stages with stages in the DP, the solution procedure moves from stage to stage working backward from the point of consumption where readiness output occurs at the unit stage. At each stage it finds an optimal policy for each state (impacting Ao, in this case) until the optimal policy for the last stage ("N") is found. A recursive relationship relates the optimal policy at stage "n" to the "n-1" stages that follow. Once the final N-stage optimal policy has been determined, the N-component decision vector can be recovered by tracing back through all the stages. In this graphical example, the challenge is to determine the optimal allocation of a defined budget across a range of initiatives associated with these several logistics stages—considering the various constraints that may be



**Figure 20**

imposed within each stage as well—to maximize the overall goal of the system of stages, i.e.,  $A_0$ . This illustration also reinforces the crucial importance of adopting STA/RBS stock policy concepts, specifically incorporating multiechelon readiness-based sparing to realize further cost-effective improvements to the system.

Second, and central to a “dynamic strategic planning” (DSP) approach, a multiperiod model must be incorporated into logistics transformation to accommodate the extended nature of this enormous undertaking. As events unfold, a mechanism is needed to routinely update the optimal solution which, inevitably, will change over time due to the inability to perfectly forecast future conditions, consequences of past decisions that do not reveal the results expected, and the opportunities provided by adaptation and innovation as they materialize, offering improved solutions requiring new decisions. This DSP approach is, in essence, a multiperiod decision analysis challenge, which also encourages and assists in identifying, clarifying and quantifying risk to the transformation effort. Risk assessment is a precursor to risk management is needed to reduce and mitigate the inevitably disruptive consequences of any transformative effort and all the uncertainties surrounding major change.

Unlike most other planning methods that optimize a particular design based upon a set of specific conditions, forecasts and assumptions, DSP presumes forecasts to be inherently inaccurate and therefore builds in flexibility as part of the design process. This engineering systems planning approach, which incorporates earlier best practices such as systems optimization and decision analysis, has now evolved to include adapting real option analysis commonly associated with financial investment planning.<sup>85</sup> DSP allows for the optimal solution—more precisely, optimal policy—to reveal itself over time while incorporating risk management instead of locking it in at the beginning of the undertaking. A set of “if-then-else” decision options evolve as various conditions unfold. This approach yields more robust and resilient system designs that can accommodate a wider range of scenarios and outcomes than can designs narrowly optimized to a set of conditions that, though perhaps easier to engineer and manage, quickly degenerate toward instability when such conditions no longer exist.<sup>86</sup> An example of DSP applied to Army

strategic resource planning in support of the national defense strategy during the first Quadrennial Defense Review (QDR) in 1997.<sup>87</sup>

Third, in addition to DSP, a wide variety of analytical methods should be used to reduce risk during logistics transformation. “Risk” can take on different connotations depending upon the application. Accordingly, we address two concepts here:

- operational risk faced by the logistics system responding to various shocks, supply chain disruptions and mission requirements that may not have been anticipated; and
- organizational risk to the Army logistics community, including the combination of investment risk associated with new project undertakings and the larger impact of transformation uncertainties associated with organizational change at a difficult and challenging time.

Operational risk, in this decision analysis context, consists of assessing both the likelihood of a particular adverse outcome and the consequences of that outcome. One of the most important steps in this assessment is the quantification of risk. Yet, the validity of the approach commonly used—expected value—is fundamentally flawed. Expected value metrics fail to represent the true risk of safety-critical systems for which the consequences may be catastrophic, though the probability of such an event may be low. This occurs because the expected value approach equates events of high consequence but low probability of occurrence (“extreme events”) with those of low consequence yet frequent occurrence. Thus, extreme events with low probability are given the same proportional importance regardless of their potential catastrophic and irreversible impact.

Recent advances in risk modeling, assessment and management have addressed the risk associated with extreme events and the fallacy of the expected-value approach. For example, a much-improved technique, known as the risk filtering, ranking and management (RFRM) methodology, ranks risk elements based upon severity. It then systematically steps through a risk mitigation process using relevant scenario-based analyses in conjunction with risk-reduction methods, including redundancy (backup components to assume functions of those that have failed), robustness (insensitivity of system performance to external stresses) and resilience (system ability to recover following an emergency). Other, more recently refined techniques that should also be considered include the partitioned multiobjective risk method (PMRM) and adaptations of the Leontief input-output model for a comprehensive risk assessment and management framework designed to ensure the integrity and continued operation of complex critical infrastructures.<sup>88</sup>

To address organizational risk, a variety of virtual, constructive and live simulation methods, especially analytical demonstrations, field testing and experimentation, can identify early on which technologies or methods warrant further consideration. In this context, organizational risk consists of the combined effects of both uncertainty of outcomes—simply not knowing the impacts of various alleged improvements on the logistics system—and also the uncertainty of future costs incurred as a consequence of either adopting or failing to adopt particular courses of action. A recent example of this accelerating approach is the sequence of experimentation and testing adopted by the AMCOM project. The project first demonstrated, through rigorous analytical experimentation using the UH-60 aircraft in the 101st Airborne Division, the potential value of adopting RBS as aviation retail stock policy. These insightful, positive results enabled

further, more widespread field testing with several aircraft types in an operational training environment at Fort Rucker. Confidence and credibility in a new, different method have been gained through experience while significantly reducing the uncertainty initially surrounding the new initiative. Return-on-investment results clearly reveal reduced costs while still meeting or exceeding readiness goals.

The Global War on Terrorism has illuminated a wide range of vulnerabilities in existing global supply chain operations. The Army logistics community should actively participate in the ongoing “Supply Chain Response to Global Terrorism” project recently initiated by the Center for Transportation and Logistics (CTL) at the Massachusetts Institute of Technology (MIT). This project is highlighting the “dependence of corporate supply chains on public infrastructure and systems coordinated or affected by the government [that] represents new vulnerabilities for businesses now more heavily dependent on the government than previously recognized.” Using assessments from recent terrorism effects on supply chain disruption and several other historical observations, several common failure modes have been identified. The research project is now focused on developing cost-effective methods and classifying various responses for reducing vulnerabilities by improving both the security and resilience of these global networks.<sup>89</sup>

The fourth and final enabling analytical component includes the development, refinement and use of econometric/transfer function models to assist disentangling investment cause-and-readiness effect for OSD- and Army Headquarters-level resource planners and programmers. As cause-effect relationships are better understood, and as model parameters, decision variables and elasticities are refined to reduce forecasting error and improve model calibration, this capability will help quantify high-impact investments and the differential effects of various logistics drivers on readiness outcomes. As part of this project, an initial modeling capability has been demonstrated for strategic logistics program development.<sup>90</sup> Further developed and refined over time, these forecasting models can be used for both readiness prediction and determination of program requirements, and could eventually constitute part of a “Logistics Early Warning System” contributing toward the DoD mandate for a larger Defense Readiness Reporting System (DRRS).

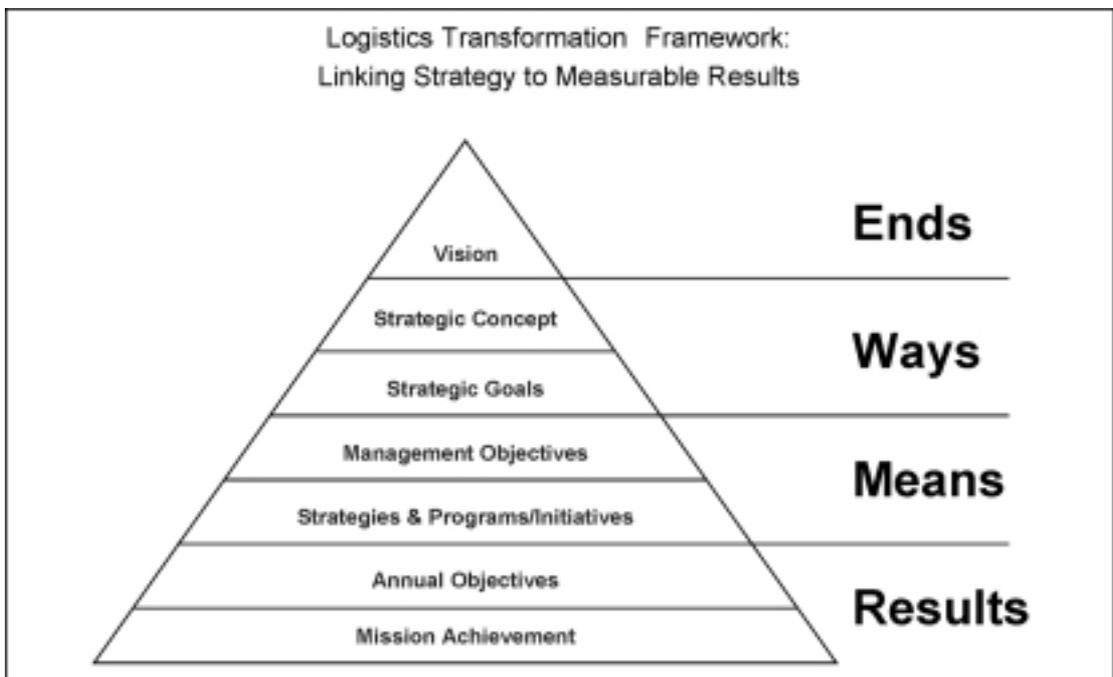
These four modeling approaches—multistage optimization, dynamic strategic planning, risk management and program development—should be used in unified and complementary ways to constitute a dynamic strategic logistics planning (DSLPP) capability. Taking as input both the empirical evidence of ongoing operations (real world results) and the potential contribution of new opportunities derived from an engine for innovation, they can guide logistics transformation toward an efficient, increasingly effective yet resilient global military supply network. Collectively, they constitute the “analytical architecture” for logistics transformation.

## **Strategic Management Concepts**

*There is no lack of hi-tech, research and development vendors offering a quick fix, or consultants bombarding corporate offices to sell their services for guiding change. Yet, in today's unsettled environment of confusion and anxiety there is a general lack of understanding of what needs to be done and how to accomplish it. . . . You cannot visualize the future if your imagination is out of focus.*

Shoumen Datta<sup>91</sup>

“Strategy is the heart of management.”<sup>92</sup> Today, however, an honest appraisal suggests existing organizational structures, relationships and logistics processes are, collectively, the product of decades of persistent work-arounds and ad hoc solutions, periodic management fads and, mostly, inertia. As with any complex, large-scale systems challenge, key integrating concepts will be essential to ensuring a successful Army logistics transformation. These organizational, analytical information systems, management concepts and technology should all be guided by a vision and supporting strategy (figure 21). Ultimately, this strategy must focus the effects of transformation upon capabilities-based, readiness-oriented outcomes. The desired end state, a characterization of the logistics organization and system following the inevitably disruptive period of logistics transformation, is that of a learning organization.



**Figure 21**

### **Organizational Redesign**

*Institutions are grounded in culture, and culture changes very slowly.*

Thomas Homer-Dixon<sup>93</sup>

Nearly 20 percent of the Army’s current acquisition workforce already is eligible to retire, and 50 percent will be within the next five years. Furthermore, the psychological effects on the remaining, predominantly civilian workforce of more than a decade of repeated downsizing and realignments cannot be discounted. Common themes expressed in interviews with officials throughout the organization are that work-arounds are endemic, ad hoc by necessity has become routine, and intense management is the standard response to compensate for chronic system

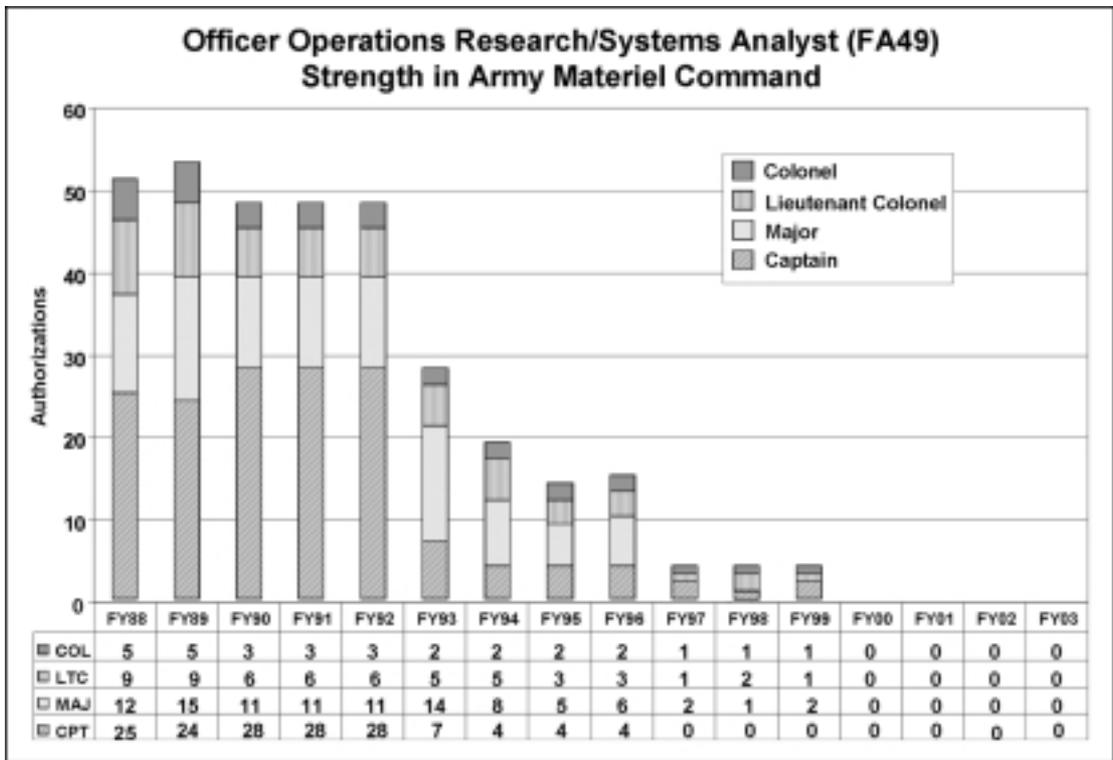
inadequacies. This surviving, dedicated and hardworking professional workforce is struggling valiantly to compensate for a system that is increasingly failing them.

An honest and forthright postmortem also begs the question of how the state of Army logistics has become what it now is. Two responses are offered here. First, the external factors credited with driving significant change in business world supply chains during the past decade are not apparent to the same degree within the DoD logistics system. These external factors included greater competition resulting from both deregulation of business structures and increasing globalization, the adaptation of information technologies to new business process needs and opportunities, and the increasing empowerment of the consumer, the so-called “Wal-Mart effect,” causing a shift in the distribution channels toward tailored logistics, value-added services, alliances and partnerships resulting in “every-day low prices.”<sup>94</sup> In contrast, while these same external factors were not forcing DoD to change comparable to the private sector, no compelling internal factors mandated change, either. Following the Cold War and the dramatic, lightning-quick Gulf War, the U.S. military was universally acknowledged as “top dog.” It had no incentive to change because, until recently, no clear evidence existed of either imminent or evident failure.

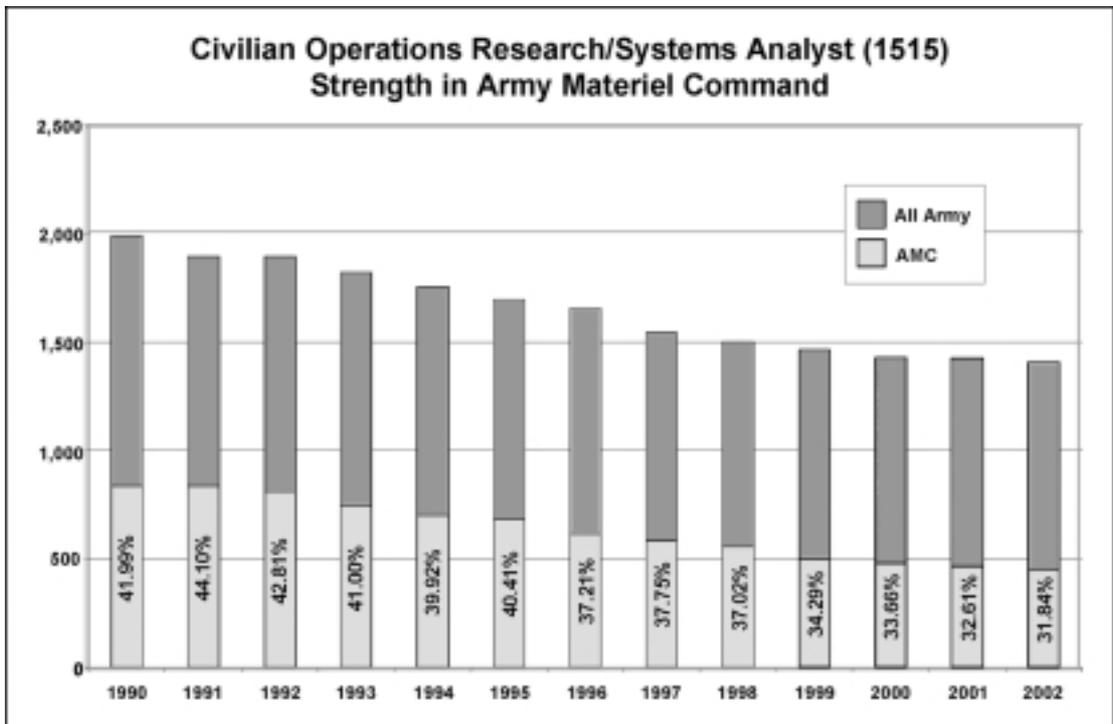
A second, complementary explanation suggests that, in retrospect, the military drawdown during the 1990s decimated the existing analytical brain trust of logistics-focused, military operations research/systems analysts within AMC. Officer Operations Research/Systems Analyst (ORSA) authorizations (FA 49) declined from 55 in FY 1989, including five colonels, to zero by FY 2000 and have remained at zero since (figure 22). Army civilian ORSA authorization (GS 1515) also took a disproportionate share of cuts, declining from almost half of Armywide authorizations in FY 1990 to less than a third by FY 2002 (figure 23). Nearly all who remain are providing matrix customer support to program management offices as cost analysts. AMCOM had no dedicated resources to support outsourcing logistics systems analysis, research or studies for at least five years before this project was initiated a year ago. Even this effort has been funded through the AWCF and is competing directly with spare part procurement needs. The Army logistics community must organize for success, starting with an appropriate investment in analytical reconnaissance.

Certainly, the ongoing effort to merge previously separate acquisition program management offices with AMC sustainment commodity commands into new Life Cycle Management Commands (LCMCs) better supports the as-yet-unrealized concept of life cycle management.<sup>95</sup> Transforming existing materiel management centers from managing supply levels for individual items to managing readiness for weapon systems would be consistent with implementation of a multiechelon, readiness-based sparing approach. More important, this would realign organizational structure toward the desired goal of relating investment levels and policies at the wholesale and retail levels to readiness-oriented outcomes.

The shortfall in DLR surge repair capacity in the existing AVCRADs organizational design and mission concept, discussed previously, is now both evident and recognized. A new capabilities document for a Mobile Aircraft Sustainment Maintenance Capability (MASMC) currently is being processed through Joint Requirements Oversight Council (JROC) validation and approval milestones. This new concept emphasizes the versatility for both a sea-based and land-based capacity to better and more responsively support an expeditionary capability,



**Figure 22**



**Figure 23**

especially during the initial deployment phase when seaports or airports may not be available. A historical precedent exists for the sea-based concept: USNS *Corpus Christi Bay* served as a floating aviation maintenance and repair platform off the coast of Vietnam from 1966 to 1975. Resurrecting such a concept today would also be consistent with the military's evolution toward sea-basing as a practical response to the growing number of nuclear-armed regional powers, whereby mobile off-shore logistics support can be better defended against theater ballistic and cruise missile attacks.

As the new MASMC concept is reviewed and evolves, consideration should be given to adopting a force structure for the supporting multipurpose aviation sustainment brigades (the replacement AVCRADs) similar to the U.S. Army Special Forces concept. Active and reserve Special Forces groups are similarly organized, but then tailored, trained and deployed to conduct support operations in specific regions of the world. In the case of the MASMC, the concept of operation would associate each of five MASMC brigades with the five corresponding regional combatant commands: U.S. European Command (EUCOM), U.S. Pacific Command (PACOM), U.S. Southern Command (SOUTHCOM), U.S. Central Command (CENTCOM) and the newly formed U.S. Northern Command (NORTHCOM). Given the current pace of global operations, this would enable habitual association and command relationships to develop. The Special Forces model also would better suit the special expertise, modified MASMC brigade organization—which should be table of organization and equipment (TOE) rather than table of distribution and allowance (TDA) as the AVCRADs were and capabilities peculiar to the operating conditions and special challenges aviation support operations face within each unified command. Both the homeland defense (NORTHCOM) and homeland security (Department of Homeland Security) missions will continue to require National Guard aviation support that have imposed additional demand not anticipated in the original ADMRU/AVCRAD concept of 1979. This MASMC concept of operation would then provide more immediate and sustained support to each of the regional combatant commands and a dedicated brigade to support the increased demand of homeland defense and security. It would also offer additional flexibility and capacity within nondeployed brigades to support sporadic surge requirements or engage in rotational or reinforcing deployments to sustain extended operations.

Finally, though particularly urgent, creation of a “Chief Knowledge Officer” (CKO) and supporting office of resource managers, logistics systems analysts, operations researchers and strategic planners would provide the knowledge and talent base to develop, measure and monitor programs with supporting metrics that link strategy to measurable results. To fully comprehend the effects of promising new technologies and methods upon the existing logistics system, the current system's previous path—defined by history, organization, process and culture—along with its directional momentum, must be understood. While vision drives organizational goals, objectives and missions, core competencies heavily influence both organizational structure and processes. For Army logistics, this crucial core competency is central to understanding what is happening, what is likely to happen and why. Knowledge must be continually extracted from the system's hysteresis to encourage innovation and sustain organizational improvement.<sup>96</sup>

Within existing military organizational structures, this source of information collection, analytical capability and knowledge creation is sometimes found in Program Analysis and Evaluation (PAE) organizations and within joint staff (J-8) and Army general staff (G-8) structures. Such a logistics

systems analysis capability, if viewed as a core competency, could also reside in a separate Army center of excellence, much as the original Army IRO had until it was abolished in the early 1990s. Similarly, but more recently, the Navy received 2005 congressional funding (HR 4613) to establish a Navy Logistics Readiness Research Center, a partnership with academic institutions and commercial firms focused on resolving many of the long-standing, GAO-noted deficiencies by developing new models, systems and approaches, including implementation of multiechelon optimization applications for the Naval supply system. If, alternatively, logistics systems analysis is recognized as needed but not deemed a core competency and, therefore, appropriate for outsourcing, a third option would be to create a convenient but durable relationship with a consortium of partners and expertise that could be called upon as needed.

While many of the structural barriers to integrated supply chain management are organizational, limiting logistics transformation to these planned and suggested redesigns of current organization and force structure will undoubtedly prove insufficient. Both organization *and process* must follow strategy.

### **Contributions of (Transactional) Information System Technology and (Analytical) Operations Research**

For many businesses, the scope, flexibility and performance of enterprise planning systems has been far less than desired and implementation unexpectedly difficult. It is crucial to differentiate among the purpose, forms and functions of analytical operations research (OR), which essentially comprise knowledge-based decision support systems (DSS), and transactional IT, which is concerned with acquiring and processing raw data and the compilation and communication of reports. While the effort required to replace a legacy modeling *system* may be considerable, overcoming barriers to legacy *thinking* about supply chain decisionmaking—the analytical component—is a more difficult and challenging task because it requires overcoming human and organizational barriers to achieve fact-based decisionmaking.<sup>97</sup>

Basically, an ERP system is a grouping of software modules that interface with a common database. As numerous case studies have noted, ERP implementations both illuminate and transform organizational processes. All too often, disaster is courted and occurs when ERP solutions are undertaken without comprehensive understanding of these underlying processes. The clear lesson drawn from these many case studies is that an ERP implementation is first and foremost an organizational management challenge to create *new* business-process designs, and only secondarily to install software systems to support those new designs.<sup>98</sup>

OR, with its roots in multidisciplinary teams applying scientific methods to military operations, has been defined as the “science and technology of decision making.”<sup>99</sup> It is the discipline of applying advanced analytic frameworks for dealing with complexity and uncertainty, especially in large-scale systems and organizations. Its purpose is to assist managers and executives with their decisionmaking processes by furnishing insight and guidance using advanced analysis. In essence, it is about the creation and management of productivity gain, and thus has been described as the “productivity gain engine” used to help organizations achieve their full potential. A recent article published by the Institute for Operations Research and Management Science (INFORMS), the professional organization for OR and management science, describes it as follows:

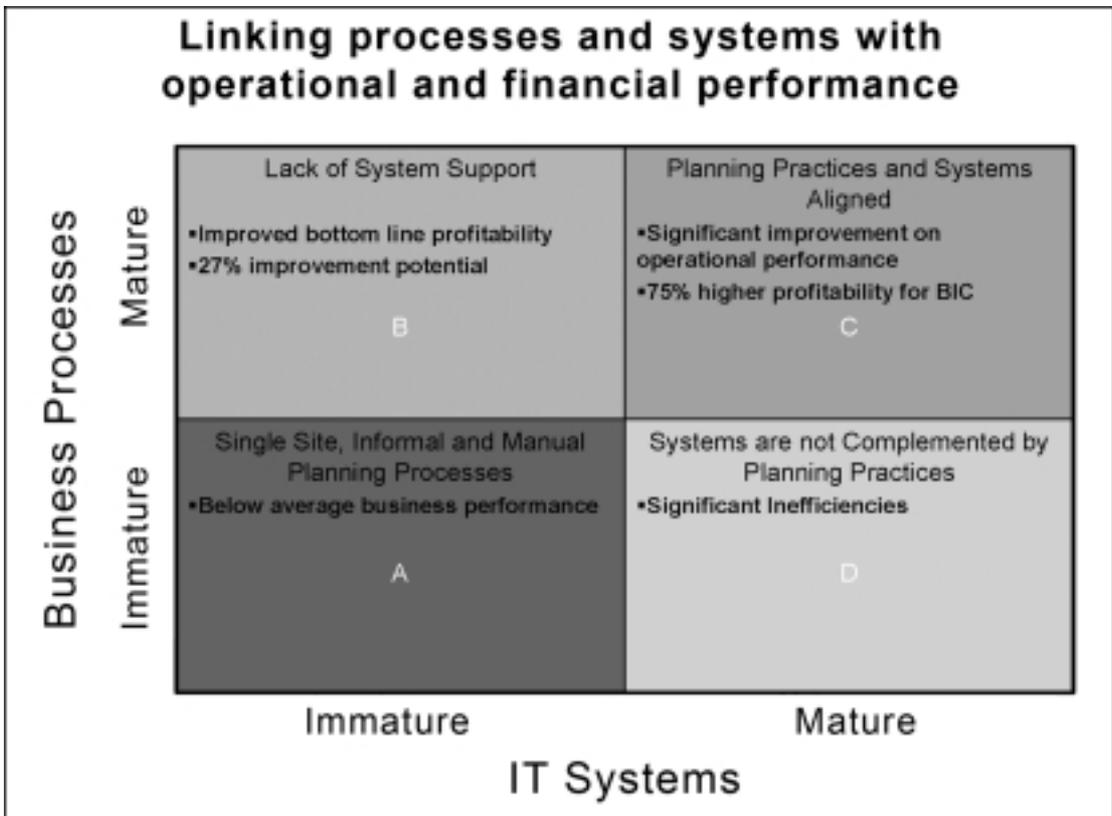
To raise the question of improvement in an organization's productivity without taking full advantage of all that OR offers would be analogous to pursuing a required improvement in one's health while ignoring the entire medical community. The realm of OR is productivity gain.<sup>100</sup>

This medical analogy is pertinent in the use of supply chain concepts to help diagnose root causes, the many suggestions and recommendations which, collectively, comprise remedies to alleviate short-term symptoms and, most important, a set of genuine prescriptions to cure the underlying illness and fully heal Army logistics.

Recently, the phrase "The Science of Better" has been adopted by INFORMS. Its professional conferences and workshops continue to focus on a worrisome trend occurring in large-scale, complex organizations. Without reengineering business processes using the analytical, integrative power of OR, the growing obsession with IT may result in increasingly complex systems that exceed the interpretive capacities of the organizations responsible for developing and using them—an example of an ingenuity gap described below. IT solutions now have ubiquitous appeal with enormous investment levels to substantiate this growing, widespread trend. Driven by increasing awareness and recognition that effective management of the entire supply chain can lead to sustainable competitive advantages in the corporate sector, the percentage of firms actually achieving such competitiveness is remarkably small.<sup>101</sup>

One recent major research effort focused on better understanding what might be causing this result and identifying those supply chain transformative strategies that differentiate the few successful firms from the many that are not. Involving case studies of 60 companies and 75 different supply chains, the research attempted to determine whether a direct correlation existed among business process maturity, IT infrastructure and investment levels and supply chain performance. The experimental design was unique in that it enabled empirical results to differentiate cause and effect: could financial performance results be attributed to improvements in business processes, IT investment levels, neither or both? The research indicated that those companies with existing appropriate, mature business processes (directly related to the firm's long-term strategy and business objectives) that had invested in IT solutions enjoyed significant operational performance improvements and financial profitability. However, this result occurred in less than 10 percent of the companies evaluated. Those companies that focused on reengineering business processes without implementing associated IT solutions were not nearly as successful as those that did implement IT solutions, yet still improved performance by more than 25 percent. However, those companies that tended to substitute IT solutions for relevant business processes or reengineering to properly align the organization to its business objectives not only failed to achieve returns on their IT investments but also declined in relative performance (figure 24).<sup>102</sup>

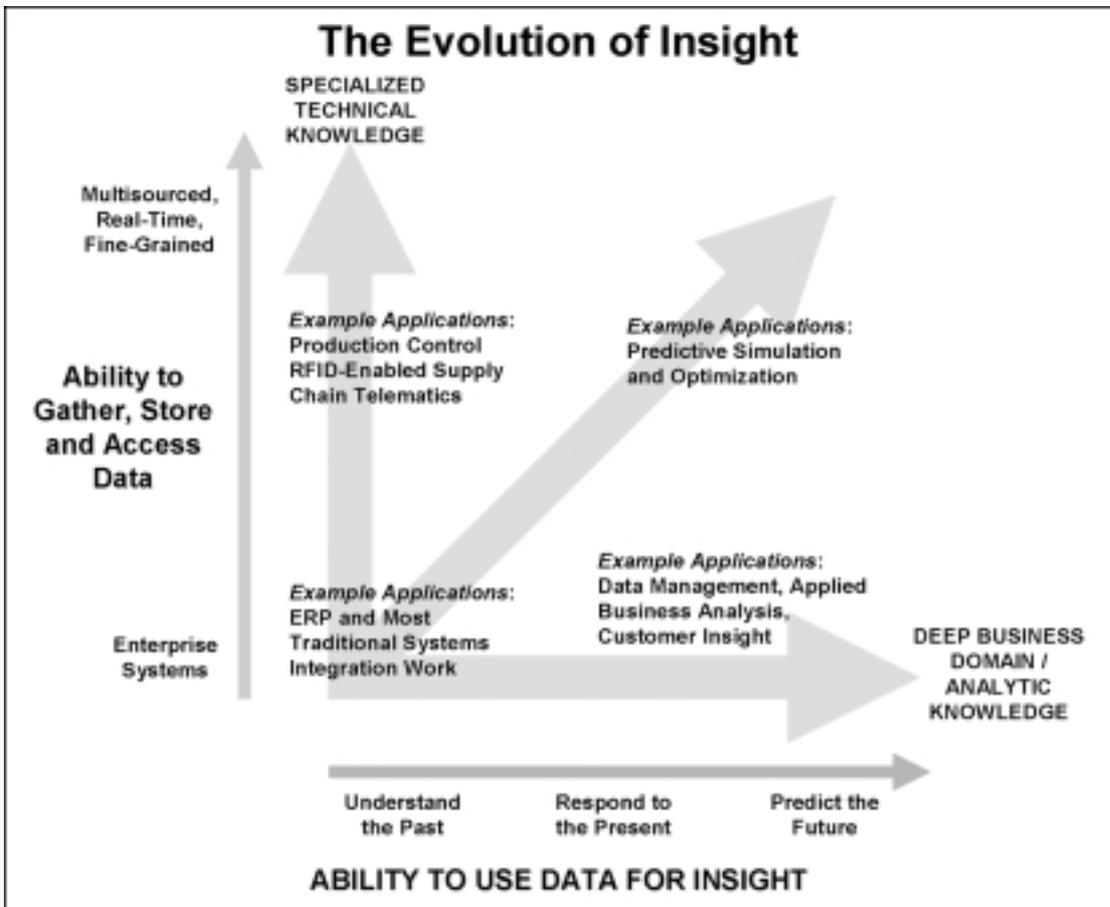
Numerous efforts also are under way to transform supply chains within the government. One partially successful effort over the past 15 years involves the \$2.3 billion defense medical logistics community. While earning several accolades, including the Hammer Award in 1998, the effort has also encountered several challenges and documented major concerns as lessons learned. Although business process reengineering was officially a prime objective from the program's inception, it was not clear who had ownership of the effort. According to case study results, many managers tended to allow technology to drive the reengineering effort or were tempted to



**Figure 24**

simply automate existing processes rather than improve the process *before* applying the best technology. Several PMs were pressured to produce results quickly and performed only cursory business process reengineering (BPR) efforts, and risk-averse managers were reluctant to invest in outcomes they would then be obligated to achieve within a bureaucratic organization with diffuse responsibilities.<sup>103</sup> These observations are instructive for AMC today, given the enormous investment in the Army Logistics Modernization Plan (LMP) and the larger Single Army Logistics Enterprise (SALE) initiatives.

Driven by various forms of information systems and decision technologies, the accumulating evidence from supply chain transformation experiences is now clear. Process rationalization initiatives (discrete reengineering efforts) and information technology integration, when combined, for example, in ERP solutions, may reduce transaction costs and provide other logistics savings. Conversely, they may also create information glut. Hence, for large-scale, complex organizations, the greatest return on investment is derived from the creation and implementation of new DSS that incorporate OR-based systems planning, forecasting and optimization technologies. Ultimately, this strategy will enable senior leaders and managers to generate knowledge and better decisions from the growing amounts of information made available by advances in information systems technologies. As mounting evidence suggests, the source of real advantage does not lie simply in procuring information technology but in the business model itself and organizational ability to convert information into insight (figure 25).<sup>104</sup>



**Figure 25**

### Strategic Management Concepts and the Learning Organization

*Managing by anecdote is no better than managing by averages . . . [and] managing by averages leads to below average performance.*

Arnoldo C. Hax, *The Delta Project*<sup>105</sup>

Historically in the corporate world, competing, sequentially adopted management philosophies periodically appear, gain popularity, then recede. In contrast, an emerging school of thought suggests an alternative concept fundamentally consisting of three prescriptive, simultaneously operating and complementary approaches. The goal is attainment of an integrated management science where these approaches are placed within a larger, more comprehensive and scientific framework, one that ultimately enables emergence and sustainment of a learning organization. Each of these three serves different purposes within this framework, yet they all relate to “the theory of the firm” and should ideally be used in a complementary and unified way. Each approach emphasizes different perspectives on the organization:

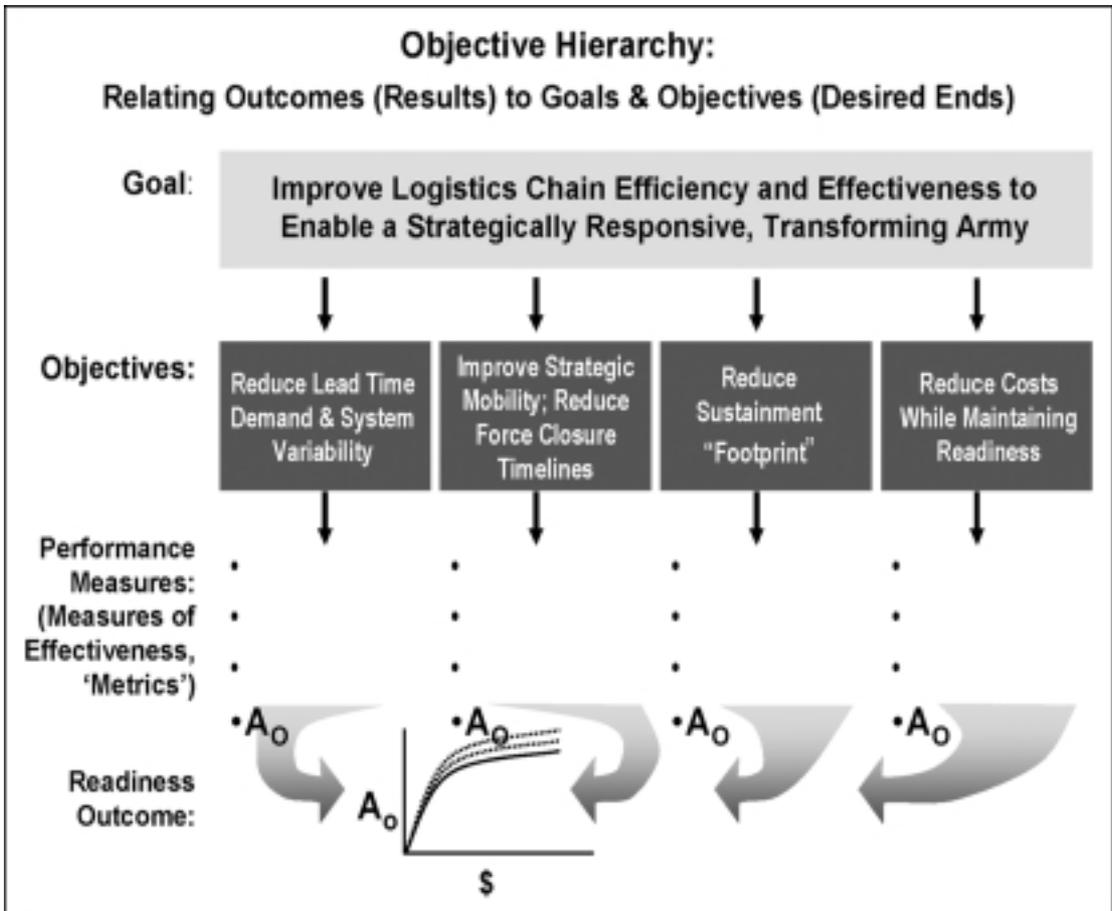
- first, a need to evaluate the short-term, internal performance and efficiency of the organization’s ability to transform resources into products or services;
- second, a more comprehensive perspective that incorporates trends and longer-term dynamic patterns, endeavoring to understand cause-and-effect relationships among the several flows—physical, information and financial—both within the organization and in relation to external factors that evolve over time and may subtly effect or abruptly shock the organization; and
- finally, the need to clearly define purpose, provide goals, nurture culture and encourage growth and improvement while situating the organization within a larger, competitive environment.

Supporting each of these organizational performance perspectives are corresponding prescriptive analytical methods:

- logical yet circumscribed, statistically based techniques, including Six Sigma, Lean and the Theory of Constraints, all of which focus on improved output quality, process and system efficiency within the boundaries of the organization;
- the domain of systems sciences, including the disciplines of systems simulation and analysis, that focus on analyzing and modeling both internal integration of and external adaptation to dynamic processes and conditions affecting the firm; and
- the more creative field of strategic planning, which has distinct quantitative aspects requiring metric-based objective hierarchies to establish meaningful performance measures and trends that can be related to the larger objectives, goals and vision of the organization.<sup>106</sup>

Aligning execution and measures associated with organizational performance to a distinctive strategy illuminates the need for adaptation and change. Such a dynamic strategic plan also provides inherent mechanisms to sense when reacting to—as well as creating—change is necessary. The value of an objective hierarchy within a dynamic strategic plan is multifold and serves several purposes by collectively aligning strategy, processes and metrics (figure 26). Descriptors for good metrics are that they be measurable to drive the collection of objective data, relevant to goals and objectives, and simple. In addition to defining performance, delineating accountability and monitoring progress toward strategic objectives, objective hierarchies also establish feedback mechanisms necessary to change a course of action when needed. Effective metrics also go beyond a narrow instrument of management control by helping to communicate organizational strategy, thereby producing greater organizational cohesion and congruency in workforce tasks. These strategy-related metrics—or performance MOEs—help reinforce the pursuit of a common vision for the entire organization. In contrast to companies or agencies that expend effort and energy trying to “measure everything”—a clear indication that they really do not know where they want to go—carefully selected metrics that relate meaningful performance to a well-developed strategy also provide insight into what an organization is truly willing to change.

While aligning strategy to successful execution is essential, these objective hierarchies and supporting metrics should all be designed with the purpose of organizational learning in mind. Recently published results from a long-term, comprehensive business strategy and management



**Figure 26**

research effort indicate that executives today, inundated with heavy doses of both anecdotal information and average performance data, nevertheless have inadequate, inappropriate, even irrelevant information at their disposal to fulfill their mandates of improving company performance in increasingly competitive environments.<sup>107</sup> With only averages as a guide, it is therefore not surprising that across-the-board reductions result from organizational reengineering efforts. Average data provides little insight into what is actually driving performance, especially in large-scale, complex supply chains subject to uncertainty and variability. Interdependent systems are characterized by information lag effects, feedback delays and nonlinearities, where small changes can amplify with large consequences. Averages mask variability in performance, yet those areas most afflicted by high variability, volatility and uncertainty clearly point to directions for improved performance. Indeed, in the face of extensive systemic and structural variability, managing short-term results to average performance metrics is not only insufficient but can be misleading and counterproductive.

Metrics, then, should be identified and selected to detect, segment and exploit underlying and perhaps previously masked variability in outcomes. This approach can then reveal a guide for

learning processes conducive to action and innovation linked to organizational strategy. This cycle consists of identifying key MOEs, then detecting, understanding, explaining, learning from and taking action based upon variability in performance. For those companies analyzed as part of this long-term management research project, this process of detecting, explaining and acting upon sources of variability was found to constitute an “important, and manageable, source of new knowledge”<sup>108</sup>—a phenomenon otherwise known as “learning.” Not only can meaningful progress and improvement be monitored with an appreciation for underlying cause-and-effect relationships, but also the feedback mechanism inherent in this cycle leads to adaptation and experimentation, which can enable effective, positive and responsive change and continual operational and organizational improvement.

## **Performance-Based Logistics for Effects-Based Operations**

*Despite spending billions on logistics systems improvements in recent decades, the results have always been less than expected and often years later than promised . . . a dramatic, coordinated effort to improve the military’s strategic supply chain planning and execution capability is badly needed.*

Roger Kallock, former Deputy Under Secretary of Defense  
(Logistics and Materiel Readiness)<sup>109</sup>

Spanning nearly a half-century now, the genealogy of DoD acquisition reform movements is extensive. The many management initiatives focused on improving system support performance and reducing costs include integrated logistics support (ILS), value engineering, design-to-cost, total quality management (TQM), concurrent engineering, CLS and, most recently, focused logistics. While the objective has been fairly constant over the decades—efficient allocation of resources to sustain readiness objectives—methods for achieving those objectives have been varied but largely unsuccessful. For example, DLA’s new “Business System Modernization” program is the sixth attempt in the past 20 years to change business processes. O&S cost growth has continued to plague all the services, especially the Army where billion-dollar shortfalls in obligation authority have caused component and parts shortages and reduced readiness for many major systems. Tactical user distrust with the supply support system has led to labor-intensive work-arounds and local solutions that, over time, induce even greater complications and inefficiencies. Finally, military logistics supply chains are inherently complex, with overlapping functions—material, information and financial flows—across independently operating organizational stages that collectively comprise the logistics support structure (figure 5, page 9).

With so many organizations and agencies having authority over their various functions and operations, accountability for integrating systemwide performance across all these jurisdictions has been nonexistent. As a former AMC commanding general recently observed, “No single manager performs the oversight, anticipatory, integrative role as a fleet manager.”<sup>110</sup> The following perspective is insightful and relevant to these ongoing challenges:

We have gone through Total Quality Management, reinvention and reengineering, downsizing and rightsizing, along with the revolution in information technology. Now people are asking us to take on process improvement, performance management,

balanced scorecards, knowledge management, and who knows what else? We face so many conflicting demands we need to figure out what our focus and priorities should be. How can we make sure all of this effort is headed in the right direction?<sup>111</sup>

The most recent official response to this crucial question is a concept known as Performance-Based Logistics (PBL), mandated by DoD Directive 5000.1 in May 2003. The resulting consequence of the chronic lack of accountability has been an inability to generate an adequate institutional sense of urgency for change. This leads to bureaucratic paralysis. However, this should not be confused with risk-averse behavior frequently attributed to senior officials who have lengthy, significant investments within their institutional environments. By failing to change they are actually incurring greater risk, not less. However, because they do not have the analytical tools needed to generate compelling arguments for change and illuminate the risk, paralysis sets in. This commonly afflicts large, complex, hierarchical organizations and is consistent with bureaucratic inertia, which has proven difficult to overcome or redirect when crises loom and failures, sometimes catastrophic, become imminent.

PBL, which encourages outsourcing logistics support functions, endeavors to prescribe and fix accountability to a single system fleet manager (the PM) by focusing on system performance outputs and readiness goals (rather than inputs and interface metrics) and reducing system life cycle costs. Fundamentally, PBL embraces free market economic concepts emphasizing the proposition that the private sector, given appropriate incentives, can outperform government agencies in managing activities that are not inherently governmental. In the private sector, the term “product support” has been used to describe a similar management philosophy of providing cost-effective maintenance and repair parts support to customers. PBL attempts to engage industry more completely throughout the life cycle of systems by giving industry partners a financial stake and incentive to maintain required readiness at minimum overall cost.

DoD and the services may have found a way to fix accountability for performance by having commercial logistics providers work for PMs and implementing performance agreements between the two. In so doing, the goal is to both improve supply chain performance and fix accountability, objectives that have been elusive despite the long genealogy of DoD reforms and initiatives. However, developing appropriate metrics and meaningful incentives for PBL agreements constitutes a new venture for DoD.

The challenge is one of aligning incentives for the logistics provider within a CLS contract so that both buyer and seller objectives can be met. The buyer—the Army’s PM—has a constrained budget within which readiness performance goals must be met. The seller—the commercial logistics support provider—is obligated to achieve results specified in the contract but also must make a profit. Thus, the CLS provider has a contract-based incentive to maximize profit while the PM must meet or exceed readiness requirements and performance objectives for the weapon system. To accommodate both objectives the CLS provider’s profit conditions must be aligned with the PM’s readiness objectives in the performance agreement specifications.

Because profit is maximized for the logistics supplier where total revenues exceed total costs by the largest margin (or where marginal costs equal marginal revenues), the challenge is to align this condition as closely as possible to the required readiness and performance goals. In

so doing, the gap between profit motive and readiness targets will be reduced. While deriving the cost function, measured in dollars, is relatively straightforward and can be accurately estimated, establishing the production function in terms of readiness and performance is difficult to quantify in dollars. Some method of converting readiness into value that can be equated to dollars is needed. This difficulty is reflected in current PBL performance agreements in which, typically, complicated scoring regimes have been developed to quantify value as output in dollars. Not surprisingly, the measures tend to reflect traditional practices. Accordingly, heavy emphasis is placed upon interface metrics such as fill rate and safety level. This approach may enable comparisons of PBL contract performance with the base case empirical evidence of supply performance, but it precludes focusing on system output performance needed to capitalize on the promise and inherent advantage of PBL.

This disconnect between supplier objectives (profit) and PM performance is a direct consequence of the metrics used in the scoring regime. In an actual case, only 30 percent of the metrics chosen actually related to readiness parameters (NMCS and Ao) while the remaining 70 percent were all related to fill rate supply performance parameters. The CLS did, in fact, achieve the mandated 85 percent fill rate goal, which reflects the preponderance of the scoring regime incentives (the award fee). But, as emphasized earlier, although the 85 percent fill rate yielded maximum profit, the disparity between seemingly “good” supply performance interface metrics and actual supply system readiness outcomes is truly dramatic: actual readiness performance achieved after contract implementation was less than 30 percent compared to the PM’s goal of 90 percent.<sup>112</sup>

Although the emphasis has been placed upon system readiness as a performance objective in PBL, other key performance objectives include reducing battlespace support footprint and reducing operating and life cycle costs. The lesson for future conflicts, demonstrated in both OEF and OIF, is to limit the physical presence of support forces and materiel. This improves force agility by reducing deployment times, intratheater lift requirements and force protection resources. The desired effect, consistent with effects-based operations, is to minimize the logistics footprint within the battlespace while maintaining effective sustainment. This can best be achieved by adopting demand-driven supply networks that require sparing-to-availability and mission-based, empirically derived demand forecasts. While these methods could explicitly be incorporated into PBL contracts, it is also likely that the logistics provider, given the latitude and encouragement to do so, would adopt such concepts anyway because they are resource-efficient methods of achieving effective results.

Recent pressures for cost reduction in the Army have resulted in sustainment engineering funding levels too low to adopt many improvements to increasingly aging fleets. In private industry these improvements would be considered as capital investments with the return on investment being greater mean times between component failure and unit replacement and fewer requirements for component removals and repairs. This paper earlier referred to this concept as reliability design to readiness. However, no such mechanism or incentive is available within the Army due to the current structure of the financial management and appropriations processes and the perception that military technicians and repair mechanics are a free good.

In the congressional budget process, investment funds consist of RDT&E and procurement. Allocating appropriate amounts of these funds to sustainment engineering (Systems Sustainment and Technical Support funds) could potentially yield large O&S cost reductions. However, these funds compete in funding categories with other major acquisition programs. In a rational process, these stovepipes would not inhibit capital investments to reduce future costs. Nonetheless, such investments find few supporters because the competition for available investment funding traditionally has favored improved capabilities (new weapon systems) over reduced operations support and manpower costs. Additionally, the Army's existing financial management system—the AWCF—precludes rather than encourages efficient behavior. As a result, repair costs have been rising precipitously for a decade, and outrageously high prices have been charged to the customer, adversely affecting readiness. Ultimately, the customer—Army combat organizations—bears all the consequences and risks of this dysfunctional system.<sup>113</sup>

Under the new DoD PBL mandate, PMs

shall be the single point of accountability for accomplishing program objectives for total life-cycle systems management, including sustainment. . . . PMs shall consider supportability, life cycle costs, performance and schedule comparable in making program decisions. Supportability, a key component of performance, shall be considered throughout the system life cycle.<sup>114</sup>

However, while PMs continue to receive RDT&E and procurement funds for acquisition, they have not been given AWCF obligation authority or Operations and Maintenance, Army (OMA) funds for procuring sustainment support. Thus, they do not yet have funding authority commensurate with their new responsibilities. Once this issue is resolved, PBL offers the opportunity to bypass the dysfunctional and paralyzing effects of the current financial management system.

PBL also has the potential to overcome confrontational, antagonistic relationships that have characterized contracting between the government and commercial providers. What is now needed to accelerate PBL is a trusted agent, an objective, neutral, mutually respected, analytically based third party who can negotiate performance agreements with confidence. The challenge confronting successful implementation of PBL as a new operating principle and management philosophy is analytically aligning the incentives within the contract to achieve readiness outcomes and performance results. This could lead to a transparent, mutually understood, objectively derived way of generating performance agreement outcomes that link price, cost and incentives to readiness and performance.

The analytical methods, logistics models and supply chain simulation capacity are available today, though not currently used by Army logistics analysts or program managers. The Army should adopt this approach expeditiously. Once it has been implemented, PMs will rely upon this trusted third party to generate performance agreements with appropriate metrics and the ability to see the impact on readiness and performance by allocating their resources under different incentive scoring regimes. CLS providers, likewise, would depend upon a mutually trusted third party to analytically determine best methods and innovative approaches to improve logistics support, meet contract performance goals and maximize profit. This third party thus becomes the honest broker and analytical glue that enables PBL to succeed, proliferate and become a

dominant, sustained standard practice across the Army and DoD—potentially a first in the long genealogy of defense acquisition reform initiatives.

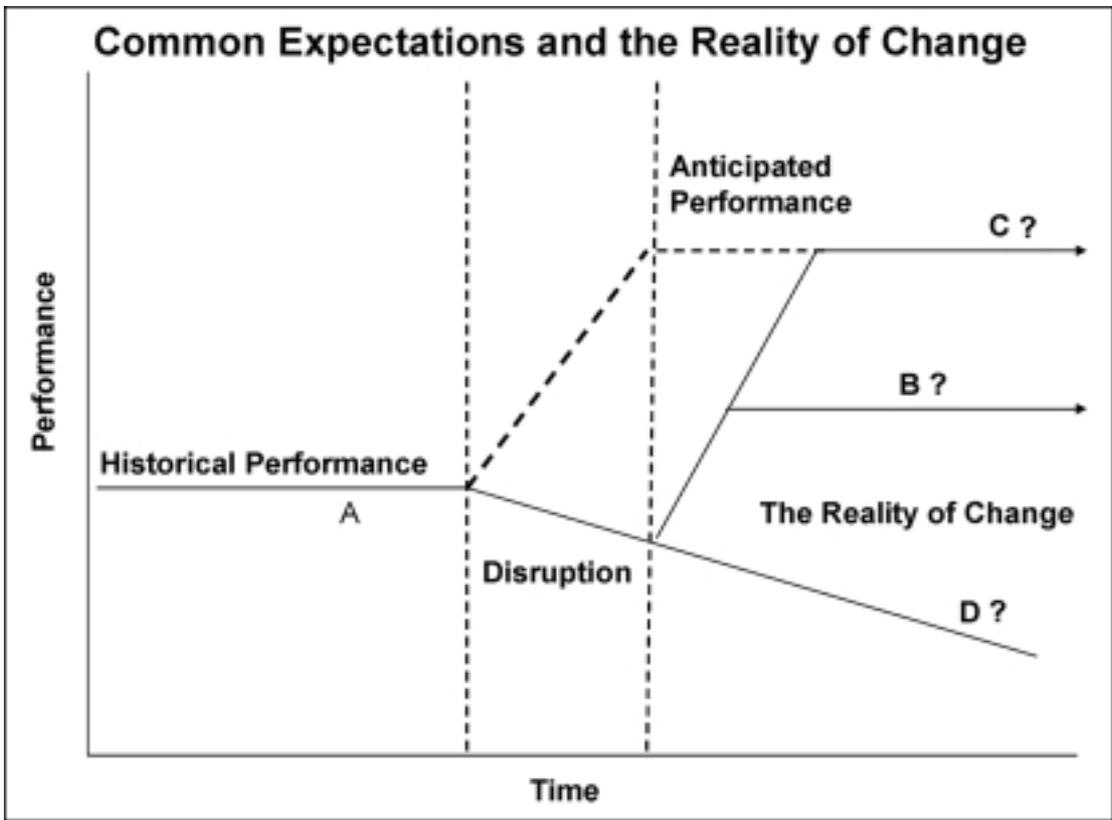
### **Logistics Transformation and Disruptive Change**

*We want to change the logistics system. Logistics has always been central to the military. But it's also been a drag on what the military can do. And right now, it's a drag on transformation because so much money and so many people are absorbed in logistics processes, that we need to reach for new constructs.*

Vice Admiral Arthur Cebrowski<sup>115</sup>

One military logistics analyst recently noted that “supply chains for contingency operations are complicated by the dynamics, risks, and uncertainties of these operations, which make it particularly difficult to establish metrics for logistics functions.”<sup>116</sup> In addition to the challenges posed by executing contingency operations while also transitioning toward the adaptive network concept of Sense-and-Respond Logistics, accelerating innovation by infusing major new technologies will inevitably lead to disruptive change. Managing expectations for organizational performance during such a period of change requires strong, determined leadership. Common directional understanding throughout the organization must be generated by shared vision and a strategic implementation plan. Change, frequently undertaken without a guiding process, can easily create initiative overload and organizational chaos. Attempting to orchestrate unmanaged change leads to cynicism and burnout as good ideas proliferate and the workforce becomes burdened with increasingly disconnected efforts. In the absence of a change management process, the organization has no ability to subsequently explain the consequences of the many initiatives allegedly contributing to either success or failure. It becomes impossible to disentangle cause and effect, and the gap between work force expectations and actual organizational performance grows. This analytical architecture is needed as a foundation for a credible transformation strategy so that resources can be allocated to meet appropriate expectations. The history of innovation suggests the reality of change is, all too often, a failure to plan resulting in expectations of performance that simply cannot be met. This occurs especially during the period of disruption when historical performance normally declines, although only temporarily for those organizations that are ultimately successful (figure 27).<sup>117</sup>

An essential but typically undervalued aspect of transformation and organizational reengineering is the investment in and attention to human capital. DoD’s current technocentric approach is based upon a presumed “information technology-driven revolution in military affairs”<sup>118</sup> that is reflected in our transformation lexicon: “system-of-systems,” “network-centric operations,” “smart” weapons, space-based “total situational awareness” enabling an “ISR precision strike complex” to achieve “full-spectrum dominance.” One defense analyst described the consequence of this RMA as “an ability to bomb any target on the planet with impunity, dominate any ocean, and move forces anywhere to defeat just about any army.”<sup>119</sup> Nonetheless, whether burdened with disconnected, outdated and inefficient “legacy” logistics systems that cannot keep up with new operational warfighting concepts or, at the other extreme, challenged by the remarkable ability of our scientific communities to develop sophisticated systems, an ingenuity gap may be



**Figure 27**

developing: a growing inability of leadership, management and the larger DoD workforce to fully understand and cope with complex, tightly coupled engineering and information systems.<sup>120</sup> As an illustrative and relevant example:

One of the key reasons for the failure of distribution-based logistics to work in operations as massive as OIF is the incredible complexity of the system. . . . Failure in any one of the component areas of distribution-based logistics will cause problems. Failure in multiple areas, or in the case of OIF in nearly all areas, can be disastrous. This complexity is manageable, but only if the system is established and is viable.<sup>121</sup>

This growing ingenuity gap, assuming it does exist although its extent may not be well-defined, is further exacerbated within the military, especially the Army, when placed within the context of the recent decline in the use, influence and appreciation of OR. Following its introduction and operational focus in the early stages of World War II and its broad post-war acceptance, OR was incorporated and institutionalized within a wide range of Army organizations and functions, including resource planning, warfighting doctrine and land combat analyses, force structure and combat developments, manpower and personnel, acquisition test and evaluation, and logistics. OR, in these earlier decades, using the words of one of its most experienced and distinguished contributors,

relied heavily on experiments, tests and analysis of empirical data to develop a thorough understanding of processes being modeled . . . [these] *experiments were designed for learning*. Unfortunately, the Army today does “demonstrations,” not experiments as they did in [earlier decades]. . . . Relative to 1960–1995 the Army has now reduced the use of model-based analyses to address system, force design/structure, and operational concept/doctrine issue and is relying more on large field exercises and “subject matter experts” in a gaming context. . . . It remains to be seen if OR and model-based analyses will play *any* role in designing the versatile [transformed] force. [emphasis added]<sup>122</sup>

Today, for example, the Army is struggling to organize small OR teams to support operational deployments for Army combat units. At the same time OR support to the institutional Army, which includes the Title 10 functions of manning, training, equipping and sustaining (e.g., logistics), has significantly declined during the past decade. In fact, the most recent “state of Army OR” article published in a prestigious Army professional journal now excludes logistics systems analysis (LSA) altogether as a domain for Army OR.<sup>123</sup> Given the lack of *any* uniformed military OR expertise within the command responsible for LSA (figure 22, page 52), this would not appear to be an oversight but merely an accurate perception of the dramatic extent of the decline of operations research within the institutional Army.

Nor do any compensating trends appear in our logistics professional education and training programs today. For example, professional military education does not currently emphasize strategic logistics,<sup>124</sup> and advanced civil schooling programs do not yet include supply chain design, management and analysis concepts.<sup>125</sup> Technical courses emphasize the operating mechanics and administrative requirements associated with existing logistics information systems rather than understanding inventory theory, supply chain dynamics and ways to address current challenges in order to improve performance.<sup>126</sup> Finally, it is noteworthy that all of the services classify their civilian logisticians—occupational code 346—as an “administrative” rather than “professional” category.<sup>127</sup>

Above all, and despite the uniquely American proclivity for technological solutions, we must continually remind ourselves that a less-skilled military is a greater liability than less-advanced technology.<sup>128</sup>

## Conclusion

The purpose of this project is to help ensure logistics transformation as the U.S. Army transitions toward a readiness-focused logistics organization which, averting Path D in figure 27 (see page 65), ultimately follows a historical trajectory along Path C.

The future is properly the temporal focus of transformation. However, a major precept of any learning organization—even more fundamental than the five disciplines that characterize one<sup>129</sup>—is the ability to actually learn from rather than merely observe the past. Distilled to its essence, simply failing to repeat past mistakes represents the most basic form of human progress.<sup>130</sup> Because people naturally tend to see their current problems as unique and overwhelming, historical analogies can be especially helpful. They stretch and broaden our thinking and bring contemporary challenges into better focus through the long lens of history. “Out-of-

the-box” thinking today should also include “looking into the box” of the past to gain understanding and appreciation.

Accordingly, consider the following characterization:

The system lacked a clear chain of command. Agencies all shared responsibility yet no one was responsible . . . it could not coordinate and standardize [data] to a common “language.” Each bureau had raw data, analyzed for only its purposes, expressed in its terms, and responsive to its need . . . reorganizations [were] a response to crises and created the illusion of progress while merely producing confusion, inefficiency, and, most seriously, personnel demoralization. . . . Because of continual reorganizations, the bureaus had new difficulty furnishing data. . . . The situation became more complicated when records in one division differed from those in another . . . [he] found the independent, loosely related bureau financial practices a “nearly insuperable barrier to consolidation” [and] varying interpretations of regulations caused confusion. . . . He believed supply should conform to industrial and scientific principles yet lacked the authority. . . . The Army was pushing an already strained supply system into a state of paralysis . . . an integrated supply system remained a myth . . . by the end of the war he feared the supply system would collapse . . . [after the war, congressional] hearings pinpointed the supply problem. . . . Yet their Act did not unify the system. It institutionalized divided authority, providing enough checks and balances to paralyze action.<sup>131</sup>

This extract is from Phyllis Zimmerman’s biography of Major General George W. Goethals, the Army engineer who designed and managed construction of the Panama Canal.<sup>132</sup> Today, a century later, this achievement is still recognized as one of the greatest engineering project management feats in modern history. At the beginning of America’s entry into World War I Goethals was recalled from retirement to head the Army’s supply organization. While his frustration expressed above may sound as if he were referring to 2005, today’s logisticians have one major advantage compared to conditions of almost a century ago. The “Power of Analysis”—OR, systems analysis, management science—did not exist then to help Goethals with his enormous supply chain management challenges. This truly incredible power is, however, at our disposal today. Will we harness it now to full advantage for the Army?

## Endnotes

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- <sup>2</sup> Greg. H. Parlier, Colonel, USA, “Enabling a Strategically Responsive, Transforming Army: A Systems Approach to Improve Logistics Chain Efficiency and Effectiveness,” briefing, Army Aviation and Missile Command (AMCOM), 2003. This, the final briefing for this original AMCOM project, is available upon request from the author: gparlier@knology.net; (256) 325-1974.
- <sup>3</sup> “High Risk Series: An Update,” U.S. Government Accountability Office (GAO) Report (Washington, D.C.: Government Accountability Office, January 2005).

- <sup>4</sup> *Ibid.*, p. 66.
- <sup>5</sup> “The Army Needs a Plan to Overcome Critical Spare Parts Shortages,” U.S. GAO Report 03-705, (Washington, D.C.: Government Accountability Office, June 2003), pp. 1–4.
- <sup>6</sup> Daniel Goure and Kenneth A. Steadman, “From Factory to Foxhole: The Transformation of Army Logistics” (Arlington, Va.: Lexington Institute, April 2004), p. 6.
- <sup>7</sup> Michael Wynne, Principal Deputy Under Secretary of Defense (Acquisition, Technology and Logistics), speaking at the AUSA Logistics Symposium, Richmond, Va., 22 April 2003, quoted in “The New Paradigm: Bringing U.S. Army Logistics in to the 21st Century,” *Torchbearer National Security Report*, (Arlington, Va.: Association of the U.S. Army, April 2004).
- <sup>8</sup> “Preliminary Observations on the Effectiveness of Logistics Activities during Operation Iraqi Freedom, U.S. GAO Report 04-305R, briefing to the House Appropriations Committee, Subcommittee on Defense, 6 November 2003, p. 14.
- <sup>9</sup> An excellent critical summary is the plenary briefing “Has IT Made OR Obsolete?” by Gerald G. Brown, presented at the Annual INFORMS Conference on OR/MS Practice, “Creating Value in the Extended Enterprise,” 4–6 May 2003.
- <sup>10</sup> Claus E. Heinrich (Member, SAP Executive Board) and David Simchi-Levi (Professor of Engineering Systems, MIT), “Is There a Link Between IT Investment and Financial Performance?” (Draft).
- <sup>11</sup> Paul J. Kern, General, USA, Commanding General, Army Materiel Command, *ARMY*, March 2004, p. 26.
- <sup>12</sup> For technology-oriented proposals supporting logistics transformation, see, for example, the 84 initiatives developed by the Army Logistics Transformation Task Force (LTF); for management-oriented concepts, see “Army Logistics Transformation,” Headquarters, Department of the Army (HQDA) G-4, January 2003.
- <sup>13</sup> Parlier, “Enabling a Strategically Responsive, Transforming Army.”
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- <sup>23</sup> Erin Q. Winograd, “What About Army Aviation?” *Air Force*, July 2001, pp. 64–68.
- <sup>24</sup> Department of the Army, Army Regulation (AR) 570-4, *Manpower Management*, 15 May 2000.
- <sup>25</sup> See Department of Defense IG Report D-2003-054, p. 8.
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- <sup>29</sup> GAO Report 04-305R.
- <sup>30</sup> Roger W. Kallock, former Deputy Under Secretary of Defense for Logistics and Materiel Readiness (L&MR), “From Factory to Foxhole,” *Supply Chain Management Review*, May/June 2004, pp. 23, 46–53.
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