contemporary issues

Enterprise Architecture: Origins, Tools, and Insights
Transforming Army Supply Chains: an Analytical Architecture for Management Innovation
Leaning the DoD Supply Chain: the DoD Activity Address Code

Contemporary Issues in this edition presents three articles: "Enterprise Architecture: Origins, Tools, and Insights," "Transforming Army Supply Chains: an Analytical Architecture for Management Innovation" and "Leaning the DoD Supply Chain: the DoD Activity Address Code."

In "Enterprise Architecture: Origins, Tools, and Insights" Captain Alice Marie Long, USAF, discusses enterprise architecture (EA), how it works, and most importantly, why it is needed. She also presents guidelines for implementation of EA, along with a synopsis of possible pitfalls in EA development.

Colonel Greg H. Parlier, PhD, USA, Retired, in "Transforming Army Supply Chains: an Analytical Architecture for Management Innovation" describes a practical approach for understanding the Army's extremely complex logistics system by introducing a systems framework which is guiding an ongoing project addressing major challenges confronting logistics transformation. The project focus is on inventory management policy prescriptions illuminated through the prism of an enterprise-wide supply chain analysis.

In the concluding article, Jay Barber, Global Logistics Support Center, USAF; Michael Werneke, Global Logistics Support Center, USAF; and Kevin P. Duffy, PhD, Wright State University, examine the efforts to introduce Lean to the Department of Defense (DoD) supply chain. A survey conducted by Manrodt, Vitasek and Thompson discovered that although Lean principles and concepts are being applied to the supply chain across numerous organizations, these principles are slow to be adopted in nonmanufacturing organizational settings. Importantly, the DoD is seen as an enormous organization, and an organization which is steeped in the traditional: the DoD encompasses ways of doing things which apply to supplier selection, organizational processes, and rigid hierarchical chains of command. Thus, the implementation of Lean principles into the DoD supply chain provides an extraordinary opportunity to examine a Lean implementation from two different perspectives. The first is that of applying Lean to a nonmanufacturing organization. The second perspective is to view attempts to implement Lean in a rigid organizational setting.

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Transforming Army Supply Chains: an Analytical Architecture for Management Innovation

Greg H. Parlier, PhD, Colonel, USA, Retired

An army fights with its weapons but lives off its logistics…

—Military maxim

So now let us embark on our enquiry into what is true … we sometimes notice that our senses deceive us, and it is wise never to put too much trust in what has let us down…

—Rene Descartes

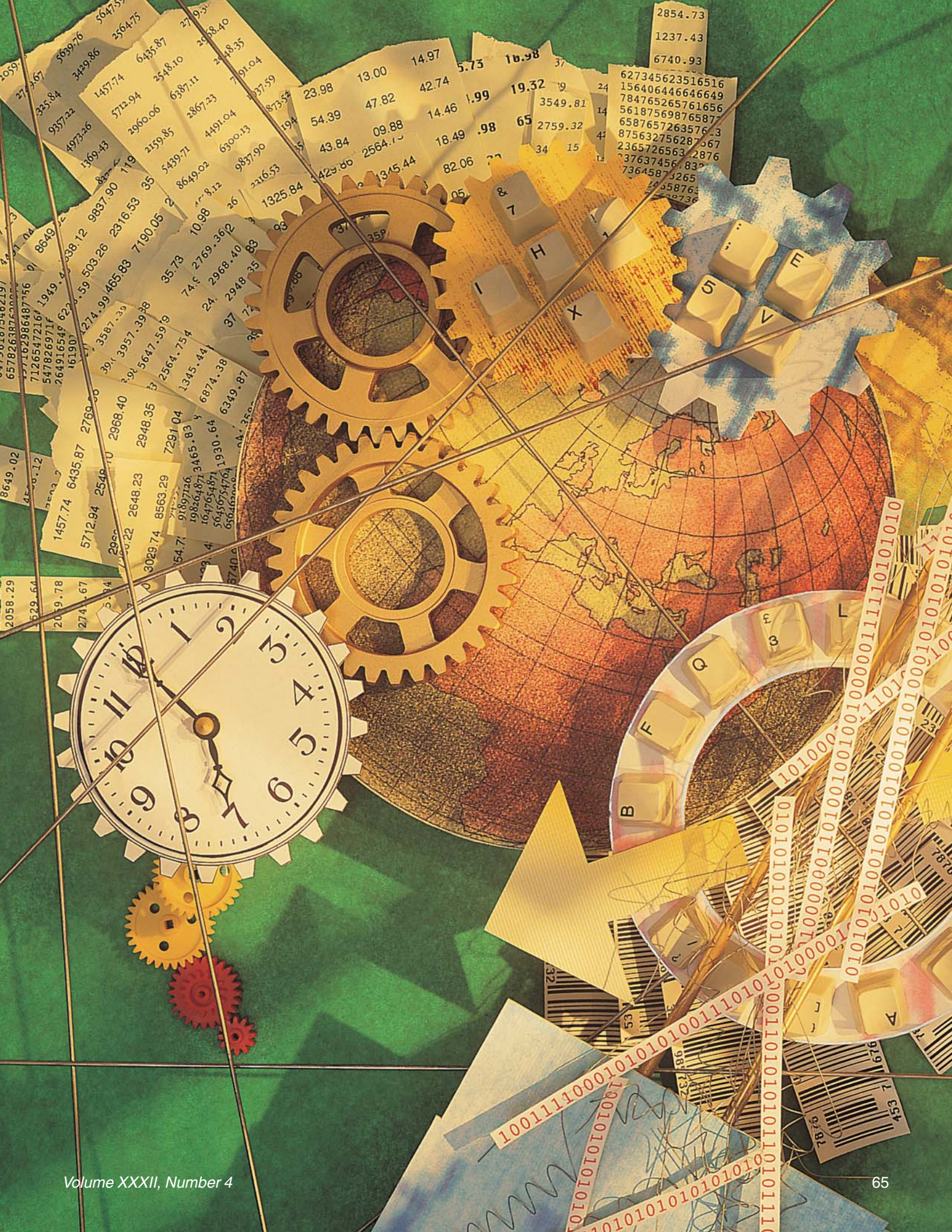
Nothing is more powerful than an idea whose time has come.

—Victor Hugo

Introduction

The US Army's logistics enterprise is truly enormous in scale and scope. However, it is not merely the size and complexity of the supply chain that causes difficulty, but rather the structure and policies within the system that are the root cause of persistent problems. Army logistics has especially suffered from several disorders which are both systemic and chronic. This ongoing research project has illuminated these problems using inventory management theory, supply chain principles, and logistics systems analysis as key sources of diagnostic power. To summarize generally, 5 years ago when the project described in this article was launched, these causal disorders and their respective effects were found to include the following:

- Lack of an empirically measured 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 contribute to poor operational and tactical support planning and cost-*in*effective retail stock policy
- Failure to optimize retail stock policy to achieve cost-efficient readiness (customer) objectives, which results in inefficient procurement and reduced readiness
- Failure to proactively synchronize and manage reverse logistics which contributes significantly to increased requirement objectives (RO), excess inventory, and increased delay times (order fulfillment) with 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 reparable components
- Limited visibility into and management control over disjointed and disconnected manufacturing (original equipment



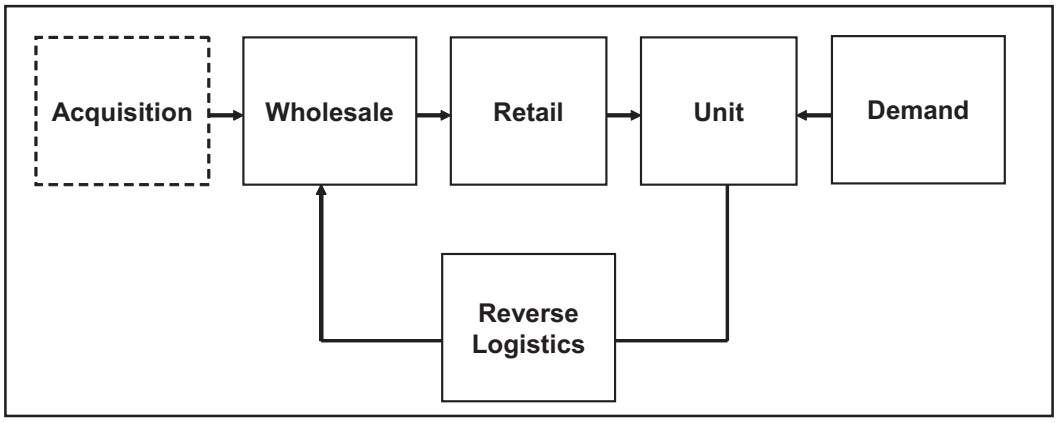


Figure 1. Multi-Stage Logistics Model

manufacturer) and key supplier procurement programs which are vulnerable to boom and bust cycles with extremely long lead times, high price volatility for aerospace steels and alloys, and 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 and vehicle fleets

- Independently operating, uncoordinated and unsynchronized stages within the supply chain creating pernicious *bullwhip* effects including high RO, inadequate stock levels, long lead times, and declining readiness
- Fragmented data processes and inappropriate supply chain measures focusing on interface metrics which 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 responses hindered by lack of an Army supply chain management science and an enabling *analytical architecture* to guide logistics transformation
- Lack of an *engine for innovation* to accelerate then sustain continual improvement for a learning organization

We found the existing logistics structure was indeed vulnerable to the supply chain bullwhip. While endless remedies have been adopted over the years to address visibly apparent symptoms, the fundamental underlying disease has not been adequately diagnosed or treated, much less cured. Now, better understanding these underlying causes of failure, a new approach to logistics management is required for the US Army.

The analytical challenge is to conquer unpredictability: to better understand their sources, then attack the root causes of variability and uncertainty within each stage and their collective contributions to volatility across the system of stages—the bullwhip effect. By improving demand forecasting and reducing supply-side variability and inefficiencies within each of the stages, logistics system performance is moving toward an efficient frontier in the cost-availability trade space.

The first step in suppressing the bullwhip effect is to isolate, detect, and quantify inefficiencies within each stage and their respective contributions to system-wide aggregate inventory RO. The next step is to use this knowledge to drive inventory policy. Since Army inventories are managed to these computed ROs, reducing the value of the RO is critical to eliminating unnecessary inventory. As recommended prescriptions for improved performance are implemented in each of the stages, their respective contributions to reducing RO (while sustaining or actually improving readiness performance) can be measured, compared and assessed within a rational cost-performance framework (see Figure 2).

In general, these various contributions to the aggregate, system-wide RO (induced by the bullwhip effect) can be isolated, quantified, then systematically reduced by understanding and attacking root causes. They include the following:

- Reducing demand uncertainty by adopting empirically-derived, mission-based demand forecasting
- Reducing supply-side lead times and their associated variability
- Improving order fulfillment while reducing back orders and requisition wait times by implementing readiness-based sparing (RBS) stock policies, inventory pooling, and ultimately, tactical-level demand driven supply networks

An especially compelling and urgent need—and also one with lucrative potential benefits—is the reverse pipeline. As retrograde operations become more responsive and contribute to a synchronized closed-loop supply chain, it becomes possible to reduce RO and safety stock for specific depot-level reparable components (DLRs) while simultaneously reducing back orders and *increasing readiness (Ao – operational availability).* As these efforts are systematically pursued, the logistics system

Article Acronyms

Ao – Operational Availability
ASL – Authorized Stockage List (used once in graphic)
CILS – Center for Innovation in Logistics Systems
DDSN – Defense Driven Supply Network
DLR – Depot Level Reparable
DoD – Department of Defense
DRRS – Defense Readiness Reporting System
DSLP – Dynamic Strategic Logistics Planning
DSP – Dynamic Strategic Planning
GARCH – Generalized Autoregressive Conditional Heteroskedstic
HQDA – Headquarters, Department of the Army
IT – Information Technology
OEM – Original Equipment Manufacturer
OSD – Office of the Secretary of Defense
PLL – Prescribed Load List
RBS – Readiness Based Sparing
RFID – Radio Frequency Identification
RO – Requirement Objective
SARSS – Standard Army Retail Supply System
SSA – Supply Support Activity (used once in graphic)
SSF – Single Stock Fund
TAV – Total Asset Visibility

becomes more efficient. RO (safety stock) is reduced while performance (back orders and Ao) is increased, thereby moving toward the *efficient frontier* in the cost-performance trade space (see Figure 3).

Efficiency, Resilience, and Effectiveness

Simply recognizing that these bullwhip conditions exist does not guarantee that needed changes will actually be made. Moreover, these debilitating and persistent effects can be avoided only if long term organizational behavior and management processes are addressed.

In addition to reducing demand uncertainty, and identifying the causes and reducing the effects of supply and demand variability within each of the logistics stages, the stages must also be integrated—linked together in meaningful ways—for credible cause and effect relationships to be identified among new initiatives. Department of the Army resource allocation investment levels can then be credibly related to readiness-oriented operational outcomes (see Figure 4).

Achieving Efficiency

A recurring management challenge in complex supply chains is determining where and in what quantities to hold safety stock in a network to protect against variability, and to 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 in order to fully understand how inventory management decisions in one particular stage or location impact other stages throughout the supply chain.

For military and aerospace logistics systems, optimizing

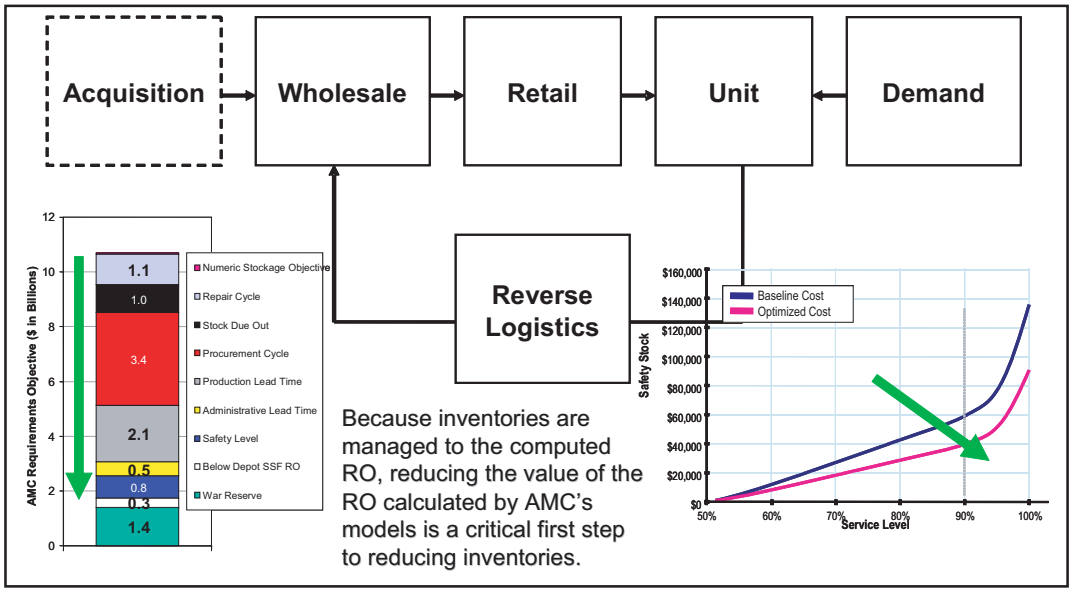


Figure 2. Improving System Efficiency—Across the System of Stages and within Each Stage

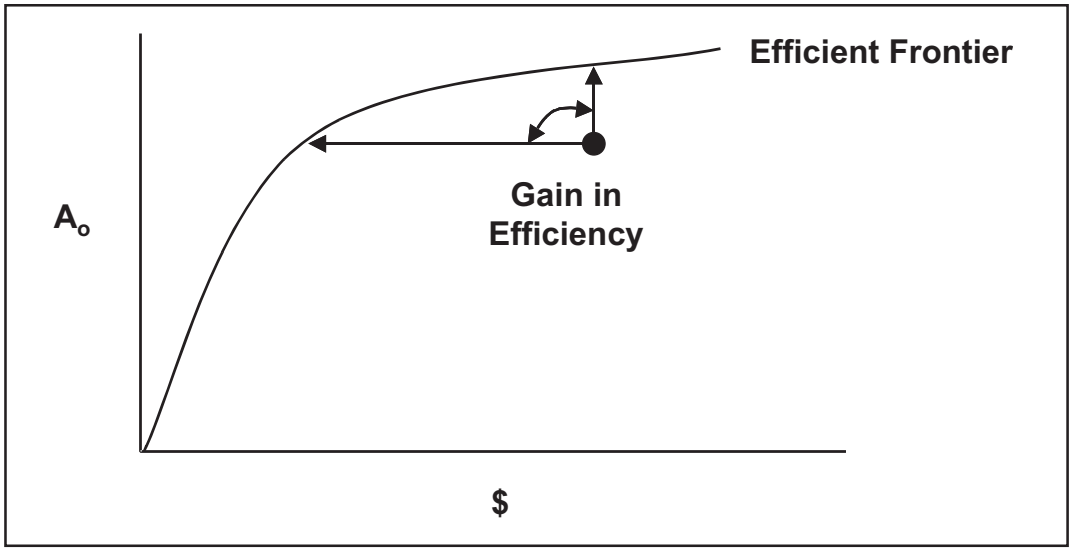


Figure 3. Achieving Efficiency in the Cost-Availability Trade Space

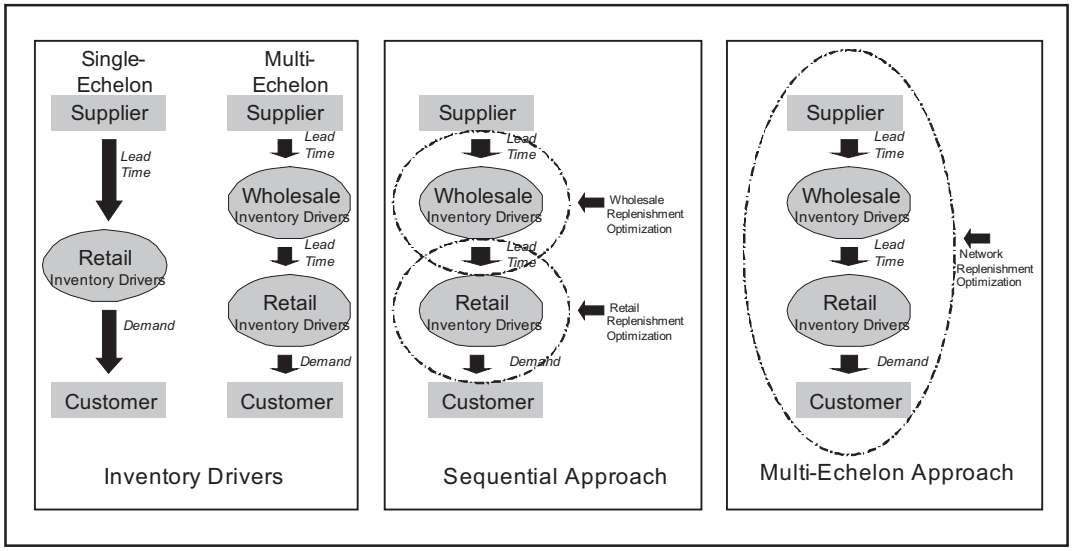


Figure 4. Multi-Echelon Integration

these decisions requires a decision support system that captures multiechelon, multi-item, multi-indenture interactions, and also the dynamics of the reverse flows for reparable components. Such a decision support system must also be linked to the various supply information transactions, depot repair and overhaul, and long term planning systems that affect the overall responsiveness, support adequacy, and capacity of the fleet supply chain enterprise—the *readiness* of the entire, globally-dispersed logistics support system.

Consequently, an integrated, multiechelon network 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.
- Its 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).
- Differentiated service levels (for example, Ao targets for different units) can be accommodated.
- Action can be taken to reduce unnecessary inventory and operational costs, while simultaneously improving readiness-oriented performance.

Although the computations to incorporate key variables, their relationships, and associated costs are certainly not trivial, they can nonetheless be performed using advanced analytic methods, including RBS optimization methods. Improved results are then possible and the organization will have far greater confidence that it is operating closer to the efficient frontier within the cost-performance trade space.

For military aircraft it has also been demonstrated that DLRs most directly relate to aircraft performance and, in general, minimizing the sum of DLR back orders is equivalent to maximizing aircraft availability. 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, the focus of practical implementation within the Department of Defense (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 existence of separate stock funds used by the Army financial management system for retail and wholesale operations. In recent years, however, these separate funds have been combined into one *revolving fund*, the Single Stock Fund (SSF). In theory, this SSF should both facilitate and encourage adoption of an integrated multiechelon approach. For example, 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 Class IX (repair parts). It now becomes possible for Army Materiel Command to incorporate multiechelon optimization for wholesale stock levels, *in addition to retail RBS solutions*, to be directly related to readiness (Ao).

It is not possible to truly *optimize* performance output from large scale, complex systems if they have not first been *integrated*. The key integrating enabler for improved efficiency in all Army weapon system supply chains (and the more complex the system, the more crucial the enabler) is multiechelon readiness based sparing. Indeed, this is a *precondition* for Army logistics transformation.

Designing for Resilience

The intent is certainly not to blindly adopt the latest management *fad* inundating the corporate world, but rather to consider adapting proven concepts to the unique needs and challenges the Army faces. The opposite result could occur with just-in-time methods. Lean manufacturing concepts have certainly helped firms to become more competitive through the application of just-in-time principles which exchange industrial age mass for information age velocity. In addition, many of the original Lean manufacturing concepts, especially the focus on reducing *stagnant* work-in-progress inventory, have been successfully adapted for supply chain management across the entire enterprise. However, the idea of *integration*, when achieved by reducing slack or waste in the system, does not necessarily enable greater flexibility.

Furthermore, just-in-time concepts, although a powerful inventory reduction method, need stable, predictable supply chains for maximum efficiency. Even when enabled by information technology (IT), Lean supply chains can be fragile, vulnerable to disruption, and unable to meet surge requirements needed to accommodate an immediate increase in demand. In fact, recent official documents describe exactly such a condition for Army logistics in recent years. Under greater duress and the compounding stress of ongoing operations, the military logistics system has indeed resulted in a Lean supply chain without the benefit of either an improved distribution system or an enhanced information system.

A more appropriate analogy for Army logistics is a flexible, robust logistics *network*; not a serial *chain* or hierarchical arborescence (see Figure 5), but rather a network *web*—as in spider web—which is then enabled by a strong analytical foundation with supporting IT to achieve an integrated, flexible, efficient, and effective logistics capability.

The research and subsequent understanding of emergence in self-organizing systems has been rapidly advancing in recent decades, extending originally from cybernetics to incorporate growing knowledge in cognitive science, evolutionary biology, dynamic systems, stochastic processes, computational theory, and culminating now in *complex adaptive systems*. For military operations, this *network-centric* future force will be linked and synchronized in time and purpose, allowing dispersed forces to communicate and maneuver independently, while sharing a common operating picture. Conceptually, the traditional mandate for overwhelming physical *mass*, in the form of a linear array of land combat forces converging at the decisive place and time, is replaced by attaining comparable *effects* derived from dispersed and disparate forces operating throughout a nonlinear battlespace.

Our ability to logistically support these concepts, especially the notion of an agile supply network at the theater and tactical levels for Army and Joint logistics distribution, may be much closer at hand now than previously recognized. At the tactical level for example, the demand driven supply network (DDSN), which includes mission-based forecasting on the demand side and RBS, lateral supply and risk-pooling (especially for depot level reparables) on the supply side, provides the foundational basis for a more agile and resilient network *web* (see Figure 6).

Through theoretical development corroborated by recent field tests, this DDSN concept has also been shown to attain *both* improved effectiveness (Ao) and, as total asset visibility (TAV) and intransit visibility (ITV) IT-based technologies are incorporated, increasingly better efficiency. Such a tactical level DDSN is not only effective and efficient, but also both resilient and adaptive, enabling a rapid transition away from the traditional hierarchical arborescence structure, which required *mountains of iron* necessary to buffer uncertainty, inefficiencies, and rigidity toward an adaptive network design consistent with sense and respond logistics.

By applying design principles for supply chain resilience, a supply chain operating a large-scale (global), demand-driven (*pull*) system under stable and predictable demand can quickly adapt to support localized, temporary requirements that may involve considerable uncertainty, but which must be *pushed* to the customer (combat units) to achieve maximum effectiveness (mission Ao in this case). Resilient design concepts include the identification of *push-pull* boundaries separating base from surge demand using decoupling points for the placement and use of strategic capacity and inventory.

These concepts suggest, first, creating prepositioned, mission-tailored support packages designed using RBS in conjunction with mission-based forecasting. These tailored mission support packages can then accommodate replacement part needs at deployed locations where existing (host nation) sustainment is not immediately or readily available. This is an example of defining a decoupling point in the existing supply chain and creating additional slack inventory to accommodate a short-term

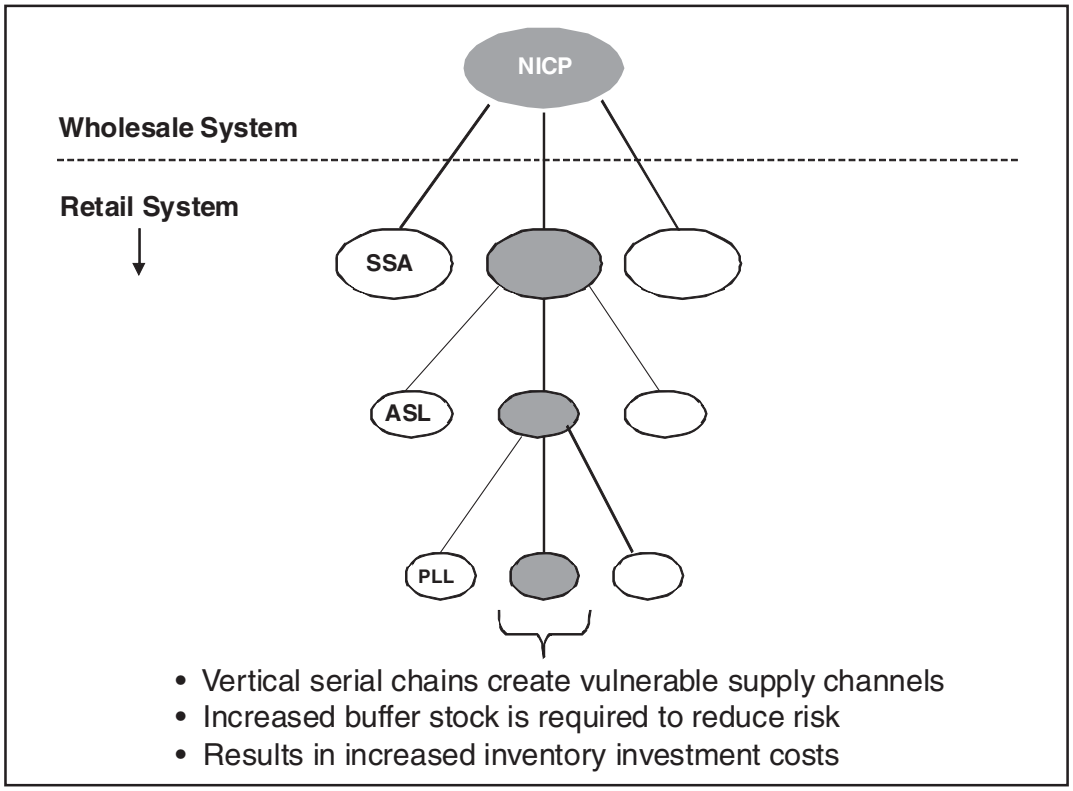


Figure 5. Current Structure: Arborescence

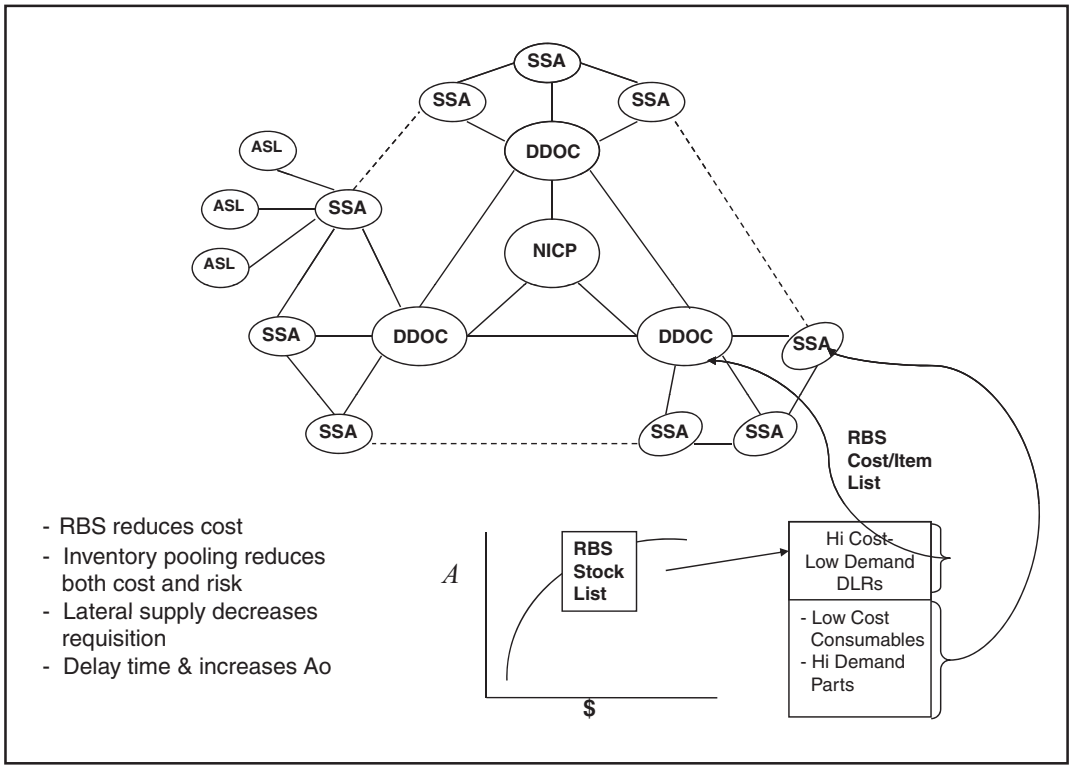


Figure 6. Demand Driven Supply Network (DDSN)

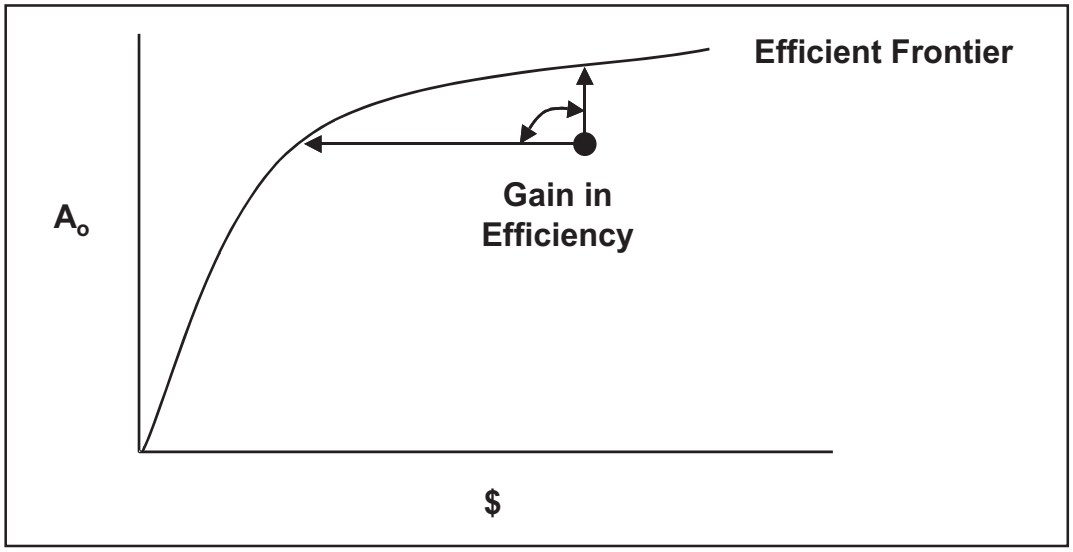


Figure 7. Achieving Efficiency in the Cost-Availability Trade Space

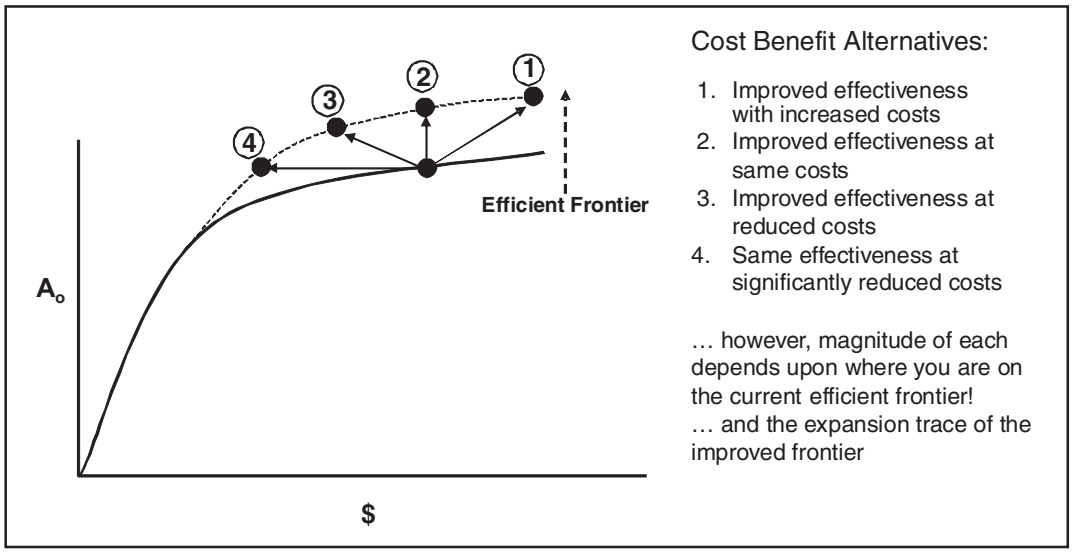


Figure 8. Increasing Effectiveness in the Cost-Availability Tradespace

surge that the existing logistics supply network infrastructure cannot immediately support.

Second, to accommodate sustained (rather than temporary) higher demand for extended operations (such as Operation Iraqi Freedom), resilient supply chain design principles suggest creating additional capacity, or relocating existing capacity, closer to the demand source. This strategic supply chain concept shifts *decoupling* points and push-pull boundaries by dynamically changing the supply chain configuration. Hence, the logistics network responds quickly to initially accommodate a short-term need with built-in slack inventory, and then adapts, if and when necessary, by actually changing its configuration to sustain increased longer-term requirements by relocating production (repair) capacity closer to the source of demand.

In summary, efforts for attaining resilience must focus on strategically designing and structuring supply chains to respond to the changing dynamics of globally positioned and engaged forces, conducting different operational missions under a wide range of environmental conditions. Ultimately, this necessitates supply chain management innovation.

Improving Effectiveness

Economists commonly make a distinction between efficiency and productivity. Efficiency refers to the output achieved from inputs using a given technology, while productivity also incorporates the results of changes in technology. By *efficient* we refer to those methods (whether policies, techniques, procedures, or technologies) which reduce uncertainty or variability both within any particular stage, as well as across the system of stages that comprise the multistage logistics enterprise. Using these methods would have the effect of moving toward the efficient frontier in the cost-availability trade space (see Figure 7). Achieving an *efficient* solution results in operating on the existing efficient frontier and implies the best possible use of existing resources *within the constraints of the current system design and business practices* using existing technology.

In contrast, a more *effective* (productive) method is one which actually shifts the existing efficient frontier, representing an improved *operating curve*. This reflects the fact that current business practices have actually changed: new or different technologies are being exploited. Cost benefit analyses can be performed on various initiatives which yield improved, but different results (see Figure 8).

Finally, the ultimate goal is to sustain continual improvement and progress over time through innovation in all of its various forms—the notion of *pushing the envelope* (see Figure 9). This is the essence of productivity gain and differentiates, in competitive markets, those commercial firms that successfully compete, survive, and flourish over extended periods from those that do not.

For a governmental activity, an engine for innovation is needed 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* which is one of several key historical prerequisites for a revolution in military affairs.

In the absence of imminent or evident failure resulting in battlefield losses which threaten the nation's interests and values,

an alternative engine for innovation is an extensive experimentation capacity providing an ability to see the impact of alternative concepts, policies and procedures, doctrine, tactics and organizational design—a virtual or *synthetic* environment that can realistically illuminate a better way, possibly preempting future failure. This experimentation capacity must also have the institutional means to incorporate positive results into new or existing policies, doctrine, and resource programs—in short, an organizational capacity that both encourages and accommodates change.

Design and Evaluation

A viable strategy is now needed to transition from the existing state of affairs to a desired outcome defined by the characteristics presented. Inherent in developing such a strategy or plan are efforts to (1) optimize the allocation of limited resources and (2) understand and anticipate in advance the consequences, likely outcomes, and risks associated with an unlimited array of tasks that must be selected, sequenced, and synchronized for implementation.

These two analytical approaches—optimization modeling and predictive modeling—must be used together in a complementary manner to illuminate a viable plan for implementation. They provide an analytically-based strategy to link means (resources) with ways (concepts and plans) to achieve desired ends (objectives): an *analytical architecture* to guide logistics transformation.

The modeling and simulation methodology outlined in the next sections will provide this much-needed analytical capacity and could constitute a *dynamic strategic planning* capability for logistics transformation. The purpose of this engine for innovation, regardless of the form it ultimately takes, is to provide large-scale systems simulation analysis and experimentation capacity and expertise needed to serve as a credible test bed. This capability will generate the compelling analytical arguments needed to induce, organize, sequence, and synchronize the many changes needed to gain momentum, then accelerate transformation for Army logistics, including those identified and described previously. The purpose, function, and relationships of key components of this enabling analytical architecture are described in the following paragraphs.

Multistage Supply Chain Optimization

Evolutionary progress for an Army logistics transformation trajectory can be easily imagined along a spectrum transitioning from legacy-reactive to future-anticipatory concepts.

- Reactive, cumbersome, World War II-era mass-based, order and ship concept where *days of supply* is the primary metric
- Modern supply chain management incorporating velocity-based, sense and respond concept where *flow time* is the metric
- Adaptive and dynamic, inference-based, autonomic logistics network concept to anticipate and lead, where the metrics are *speed and quality of effects*.

However, a clearly defined implementation scheme for transformation is certainly not self-evident. Analytical methodologies are needed to properly sequence the vast array of new initiatives, modern technologies, process changes, and innovative management policies in cost-effective ways. Which ones are dependent upon others as *enablers* for their success? How many can be done in parallel? For those that can be, will it be possible to identify and quantify the different effects of their respective contributions? Will the synergistic consequences of interactions among complementary initiatives be measurable? Which ones may be precluded by combinations of other, more cost effective options? And how can we be assured that these

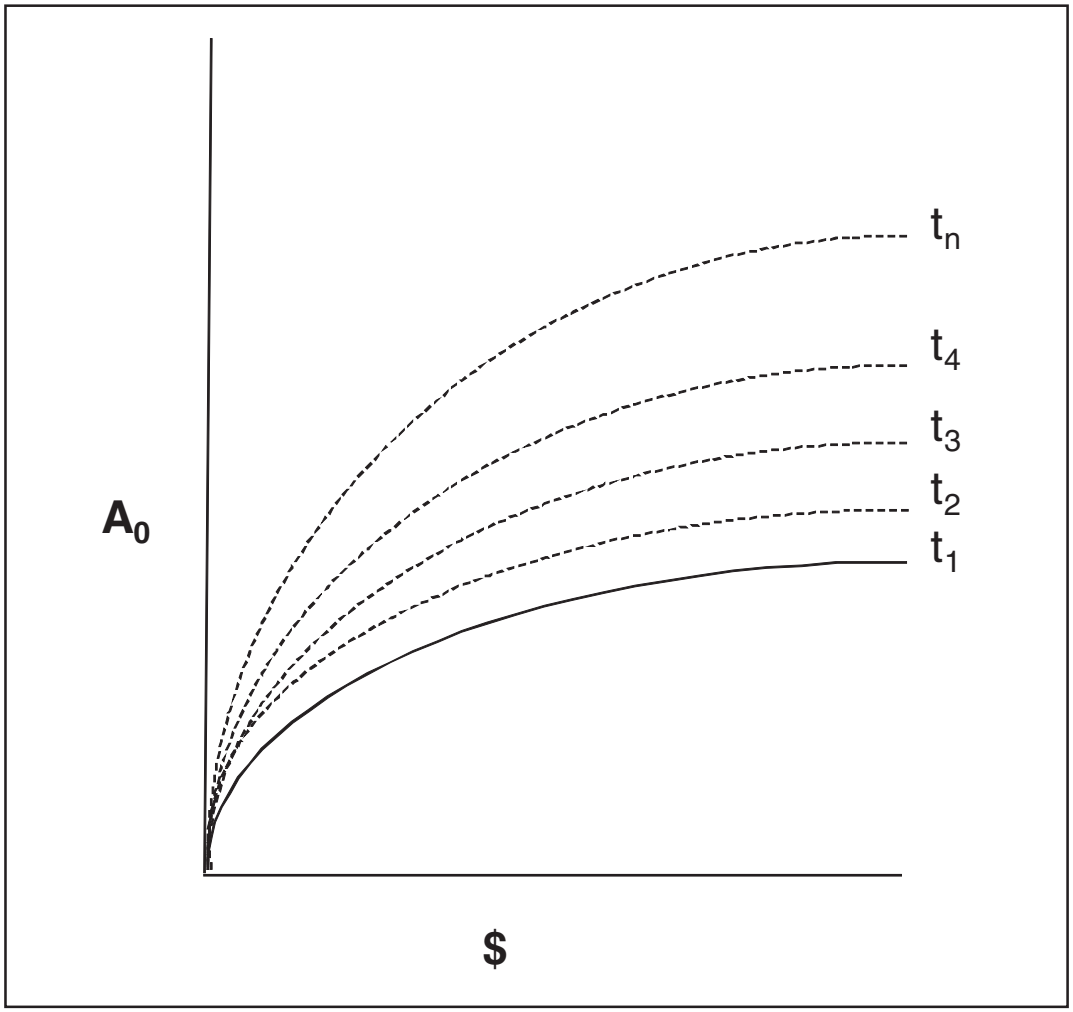


Figure 9. Pushing the Performance Envelope in the Cost-Availability Tradespace

various initiatives are not inadvertently discarded because their potentially positive effects on readiness are lost in the existing noise of such a complex, massive supply chain? In short, how can cause and effect be disentangled as transformation proceeds?

The earlier use of a multistage conceptual model to analyze the Army's logistic structure naturally lends itself to the use of dynamic programming or a comparable problem solving technique. In this multistage, 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. Consideration must be given to various constraints that may be imposed within each of the stages as well. The overall goal is to maximize output from the system of stages - readiness (that is Ao).

From a practical perspective, this approach also reinforces the crucial importance of developing a clearly defined, empirically measured readiness production function, and adopting RBS stock policies as enabling prerequisites to realize further cost-effective improvements to the system. For example, if the link between the unit stage (where readiness is produced for specific capabilities) and the retail stage (where management policy has not been optimized to desired readiness objectives (Ao) by adopting RBS), then the potential positive effects of a wide range of other improvements throughout the supply chain will not be clearly visible and fully realized. Additionally, potential investments should not be chosen on an individual basis, but rather on how they interact with each other. Otherwise, their real effects will simply be lost in the downstream noise of a very volatile, disconnected, and inefficient supply chain.

Dynamic Strategic Planning

Second, use of a multiperiod model must be incorporated into logistics transformation to accommodate both the extensive and extended nature of this enormous undertaking. As events occur and a transformation trajectory evolves, a mechanism is needed to routinely update the optimal solution which, inevitably, will change over time due to (1) the inability to perfectly forecast future conditions, (2) consequences of past decisions which do not always reveal the results expected, and (3) the opportunities provided by adaptation and innovation as they materialize and offer improved solutions requiring new decisions.

This dynamic strategic planning (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, a precursor to risk management, is needed to reduce and mitigate the inevitably disruptive consequences of any major transformative effort with all the uncertainties surrounding significant change.

Most planning methods generate a precise, optimized design based upon a set of very specific conditions, assumptions, and forecasts. In contrast, DSP instead presumes forecasts to be inherently inaccurate ("the forecast is always wrong") and therefore builds in flexibility as part of the design process. This engineering systems approach incorporates and extends earlier best practices including systems optimization and decision analysis. DSP allows for the optimal solution—more precisely, optimal policy—which cannot be preordained at the beginning of the undertaking, to reveal itself over time while incorporating risk management: a set of if-then-else decision options that evolve as various conditions unfold which cannot be predicted with certainty. This planning method yields more robust and resilient system designs which can accommodate a wider range of scenarios and future outcomes than those more narrowly optimized to a set of specific conditions. Though perhaps easier to engineer and manage, traditional optimal designs can quickly degenerate toward instability when such conditions no longer exist.

These observations suggest that large-scale, transformational endeavors are much more than conventional *construction* engineering efforts. They represent a major human enterprise where effective managerial decisionmaking requires a thorough understanding of the evolution and dynamics of the change undertaken. New software tools now make it possible for managers to actively participate in the development of these system dynamics models, so-called management *flight simulators*, which have become the basis for learning laboratories in many organizations.

Army logistics transformation will benefit enormously from such an application. Since supply chain behavior often exhibits persistent and costly instability, a stock management structure can be used to model and explain these effects. Since this structure involves multiple chains of materiel stocks, information and financial flows, with resulting time delays; and because decision rules often create important feedback loops among the interacting operations of the supply chain, system dynamics is well suited for modeling and policy design (see Figure 10).

Much of the management literature in business process reengineering emphasizes finding, then relaxing, major bottlenecks in the existing manufacturing or operations process. Focusing improvement effort on the current bottleneck immediately boosts throughput, while effort on nonbottleneck activities is wasted. However, relaxing one constraint simply enables another to develop as time progresses. Obviously, waiting for each successive bottleneck to occur would prolong and retard rather than accelerate continuous improvement. The value of system dynamics modeling is accelerating this understanding by exploring the implementation of different sequences in a synthetic (simulated) environment. By using the model to anticipate and accelerate this shifting sequence of bottlenecks, a prioritization scheme for these many initiatives can be developed. For the Army, a system dynamics model of the supply chain has the potential to guide and help accelerate logistics transformation by optimally sequencing and synchronizing the vast array of initiatives that have been suggested for implementation.

Decision analysis, the second major analytical component in the evolution of DSP, enables structuring the combination of system dynamics-enabled design choices so they can be made in stages as a system evolves over time. Cost-effective options can be evaluated to determine the best pattern for system development depending on how uncertainties, both within the system and external to it, are resolved over time. Thus, DSP defines an optimal strategy or policy rather than a fixed plan.

The most recent DSP improvements have focused on incorporating means to evaluate and build flexibility into designs. These include real options and robust design methods which enable calculation of the value of flexibility which was not previously considered. Consequently, flexibility as an attribute of engineering systems design was systematically neglected. Real options, applied to real physical systems, is an adaptation of options analysis which was developed for and has

been applied extensively in financial markets. Recent and ongoing applications of this newest aspect of DSP indicate the approach leads to substantial improvements in design. Also, embedding flexibility into diverse systems already optimized for performance under traditional deterministic concepts is leading to substantial savings in many cases.

Operational and Organizational Risk Evaluation

In conjunction with DSP, a wide variety of analytical methods should be used to understand, evaluate, and reduce risk during logistics transformation. Risk can take on different connotations depending upon the application. Accordingly, we address the following two concepts:

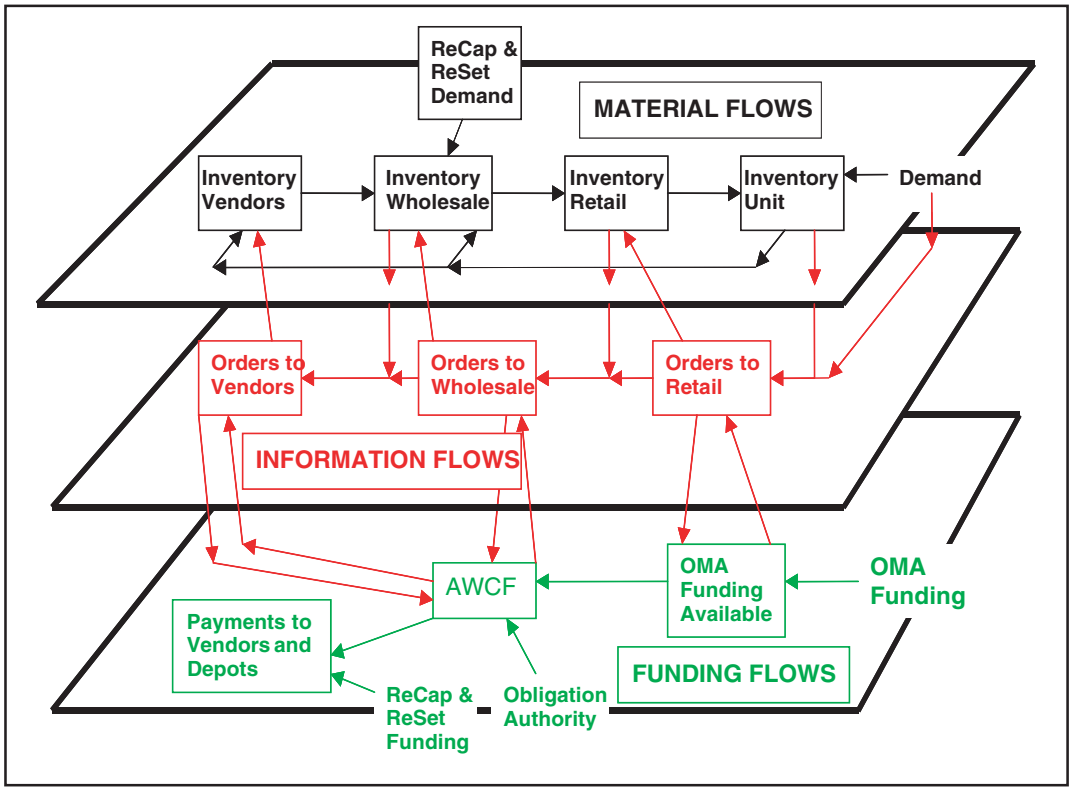


Figure 10. Supply Chain Flows

- Operational risk faced by the logistics system responding to various shocks, supply chain disruptions, and mission requirements that may not have been anticipated.
- Organizational risk to the Army logistics community, including the combination of investment, or programmatic, risk associated with new project undertakings, and the larger impacts induced by 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.

Practical management frameworks have recently been developed to systematically identify supply chain vulnerabilities, assess risk, and then formulate strategies to reduce those vulnerabilities and mitigate risk. Various sources and potential causes of disruption are then bundled into associated risk categories. Analytical *tool kits* can be applied to examine specific effects and larger consequences for these risk categories, then supply chain modeling and simulation is used to analyze, evaluate, and compare alternative operational strategies and their respective costs.

Those strategies which reduce disruptive risk and enhance supply chain resilience, while simultaneously improving both efficiency and effectiveness, are ideal candidates for accelerated implementation. Two practical risk mitigation strategies which impact all three supply chain system performance objectives (efficiency, resilience, and effectiveness) are (1) a demand-driven supply network (DDSN) which reduces buffer inventory, improves readiness, and provides tactical agility, and (2) theater-level decoupling points to enhance operational agility and flexibility by providing, respectively, *slack inventory* for short, specific mission surge needs (such as humanitarian operations) and, when necessary, *slack capacity* for long-term increases in demand to sustain in-theater operations.

To address organizational (rather than operational) risk for Army logistics transformation, a variety of virtual, constructive, and live simulation methods (especially analytical demonstrations, field testing, and experimentation) can identify early on which technologies or new methods warrant further consideration. This process enables differentiating those appropriate or sufficiently mature for implementation from other methods that are not. 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.

An example of this accelerating *crawl-walk-run* approach is the sequence of experimentation and testing adopted by this project to first demonstrate, through rigorous analytical experimentation using the UH60 aircraft in the 101st Airborne Division, the potential value of adopting RBS as aviation retail stock policy. These insightful, positive results then provided impetus for 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. And return-on-investment results clearly reveal reduced investment costs while still meeting or exceeding aircraft training availability goals.

Logistics System Readiness and Program Development

The final enabling analytical component includes the development, refinement, and use of econometric and transfer

function models. This capability is needed so that the Office of the Secretary of Defense and Headquarters Department of the Army level budget planners and resource programmers can relate budget and program investment levels with associated performance effects, including future capability needs and desired readiness outcomes. New impetus for this long-recognized need is now provided by DoD Directive 7730.65, which requires developing and implementing a new Defense Readiness Reporting System (DRRS). The Services, as *force providers*, generate and maintain military capabilities which are then provided to the regional combatant commanders to accomplish specified missions. Each Title 10 *function* consists of significant institutional resources, organizations, and programs which collectively define systems. Hence, a measure of each system's ability to achieve its respective goal can be defined as its *readiness* (for example, logistics system readiness).

Application of this systems approach using supply chain management concepts will help to identify constraints and weak links that are inhibiting desired readiness output (Ao), thus reducing the overall strength of the logistics chain. Marginal investment resources should then be spent on strengthening these weak links. OSD and the Services are pursuing many logistics initiatives, but as the supply chain structure is improved and refined, the logical next step is to understand and report the ability and capacity of the chain to generate output commensurate with its purpose.

New supply chain management concepts are incorporating geospatial sensors and automatic identification technologies to enable TAV and the transition toward adaptive supply chains. In particular, radio frequency identification (RFID) is expected to significantly reduce transaction error rates while also providing near real-time, high volume data. Although these new technologies hold great potential, it is unlikely that legacy software and enterprise resource planning (ERP) systems will be able to provide improved decision support and fully extract all of the potentially useful information contained in these high volume data streams.

Recent forecasting advances have yielded more accurate and precise results. These models, described as generalized autoregressive conditional heteroskedastic (GARCH), are able to significantly reduce the error term by better quantifying interaction and lag effects among the explanatory variables and time series within the model. As the volume of data increases, the ability of GARCH techniques to better disentangle and explain cause and effect relationships, while reducing forecasting error (unexplained model variance) improves. One project initiative involves examining the application of GARCH to RFID-generated supply demand data for units engaged in ongoing military operations in Iraq. Early results are promising, indicating that GARCH is yielding order of magnitude improvements for predictive performance compared to standard methods.

In the near term, however, driven by the new DRRS mandate and enabled by supply chain concepts, econometric modeling and dynamic forecasting to understand, measure, and monitor Army logistics as a readiness-producing system, a conceptual framework has emerged for a Logistics Readiness and Early Warning System. The purpose is not only to assess and monitor supply chain capacity to efficiently and effectively support current requirements, but also to anticipate its ability to responsively meet a range of future capabilities-based requirements as well. The objective is to overcome funding-induced instability manifested in periodic *boom and bust* cycles.

As Figure 11 portrays, three elements would interact in a *feedback-alert-warning* cycle. Automated monitoring continuously tracks and forecasts both tactical readiness (Ao) and supply chain parameters, then signals an alert if there is a decline in projected readiness or adverse trend in metrics. Management Assessment then validates an alert, quickly evaluates the potential problem, and assesses the impact of current and planned resource allocation as well as other technical initiatives which might mitigate or improve the logistics projection. After Headquarters Department of the Army (HQDA)-level policy analysis and review, policy response acts to prevent a shortfall while minimizing recognition and resource response lags. This responsive link to program development is absolutely crucial to an adaptive demand network. Historically, however, this response has significantly lagged or been missing altogether causing boom and bust cycles in resource programming, thus precluding viable resource-to-readiness frameworks for management decisions.

Further developed and refined over time, these forecasting models can increasingly be used for future capability forecasting, program requirements determination, and readiness prediction. These models should constitute part of a Logistics Readiness and Early Warning System contributing toward the DoD mandate for a larger DRRS by linking Army PPBES (Planning, Programming, Budgeting, and Execution System) to operational planning systems (readiness). The goal is to relate planning guidance, funding decisions, and execution performance in meaningful ways, all of which are informed by this supply chain health monitoring and management concept.

Accelerating Transformation

Several agencies and organizations with logistics modeling and supply chain simulation capabilities should now be integrated into a more formal research consortium to better coordinate their efforts and reinforce their respective strengths. This synergistic effort will facilitate properly sequenced field tests, experiments, and evaluation with supporting modeling, simulation, and analysis. Furthermore, these organizations should form the nucleus of an engine for innovation for logistics transformation—a Center for Innovation in Logistics Systems (CILS).

The CILS organizational construct consists of three components which essentially comprise the core competencies (mission essential tasks) for the center (see Figure 12). The three components are as follows:

- A research and development model and supporting framework to function as a generator, magnet, conduit, clearinghouse, and database for good ideas.
- A modeling, simulation, and analysis component which contains a rigorous analytical capacity to evaluate and assess the improved performance, contributions, and associated costs that promising good ideas might have on large-scale logistics systems.
- An organizational implementation component which then enables the transition of promising concepts into existing organizations, agencies, and companies by providing training,

education, technical support, and risk reduction or mitigation methods to reduce implementation risk.

These three components serve to accomplish the following:

- Encourage and capture a wide variety of inventions
- *Incubate* those great ideas and concepts within virtual organizations to test, evaluate, refine, and assess their potential costs, system effects, and contributions in a nonintrusive manner
- Transition those most promising ideas and concepts into actual commercial or governmental practice

Hence the term innovation is deliberately in the center's title to express the notion of an engine for innovation to support major transformation endeavors in the government and private sectors driven by an increasingly recognized necessity for change.

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 (DSLP) capability. DSLP can take, as input, both the empirical evidence of ongoing operational evidence (real world results) and also the potential contribution of new opportunities derived from an engine for innovation (synthetic results), and then guide (as output) logistics transformation toward strategic goals and objectives: an efficient, increasingly effective, yet resilient global military supply network. DSLP constitutes the analytical architecture needed to sustain continual improvement for logistics transformation (see Figure 13).

Collectively, CILS and DSLP have the potential to accelerate the process of management innovation by building a capacity for low-risk experimentation using a credible, synthetic environment. This cycle sustains continuous improvement through a deliberative process of incremental innovation achieved through experimentation, prototyping, and field testing.

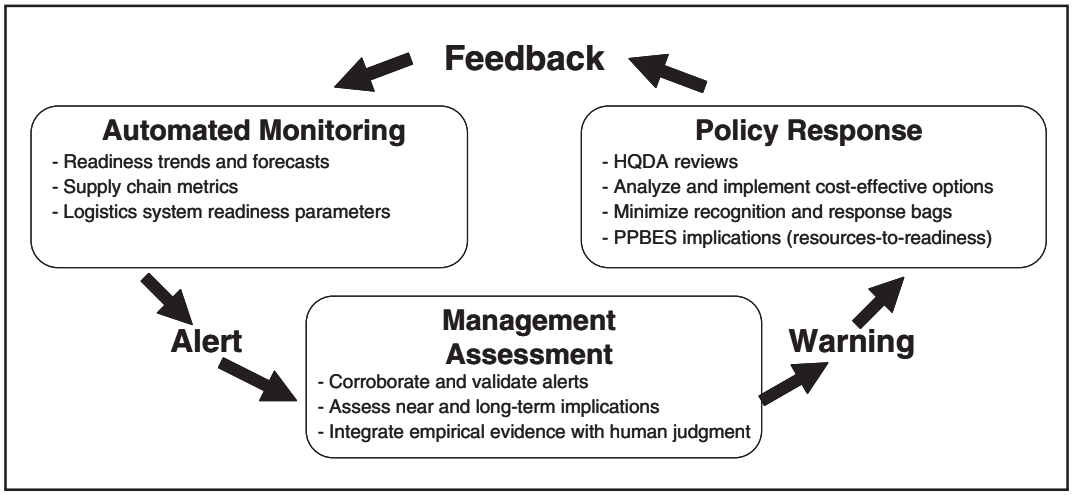


Figure 11. Logistics Readiness and Early Warning

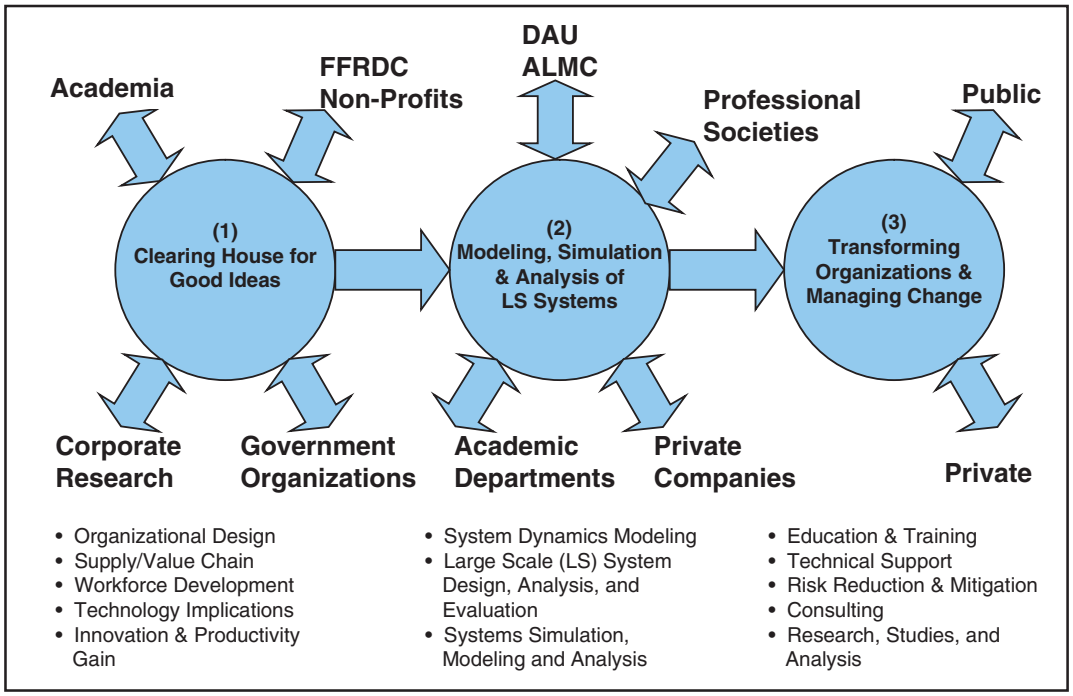


Figure 12. Center for Innovation in Logistics Systems

Final Thoughts

Tactical units in the US Army are renowned for pioneering and refining the after action review concept as a continuous learning method to surface, diagnose, and correct deficiencies in order to improve performance and sustain operational excellence. Yet comparable diagnostic effort has not been prevalent at strategic levels within the institutional Army bureaucracy. Since analytically rigorous diagnosis, understanding, and response on management issues are not routinely performed to uncover ground truth and learn from mistakes, reactive firefighting has been the standard response to visible symptoms. Army logistics management has become sclerotic.

As with any complex, large-scale systems challenge, key implementing concepts will be essential to ensure a successful Army logistics transformation endeavor. These organizational, analytical, information systems, technology, and management concepts should all be guided by a clear understanding of the

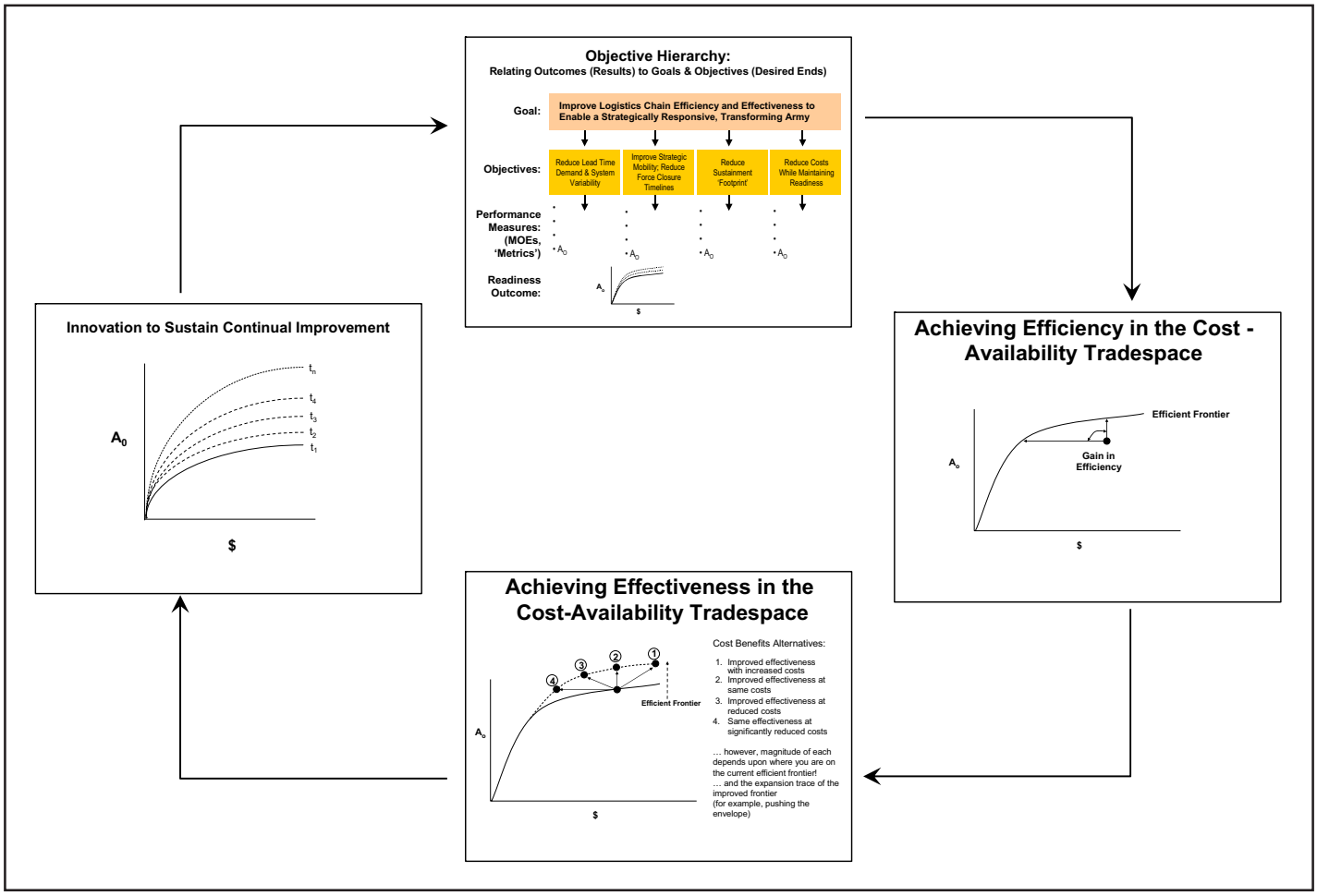


Figure 13. Sustaining Innovation While Linking Execution to Strategy

ultimate purpose for which the enterprise exists—an organizational vision for the future and a supporting strategy to realize the vision (see Figure 14).

This strategy must focus the effects of transformative change upon capabilities-based, readiness-oriented outcomes. The development of strategic planning and management frameworks are also essential to enable learning within organizations. Transformation will indeed require disturbing existing cultural paradigms, causing an inevitably disruptive period of significant change. Despite the inexorable advance of technology, it will be improved management and decision support systems that ultimately enable innovation potential to be realized. Finally, this endeavor should embrace that of a learning organization. This will be a crucial enabler for sustaining continuous improvement.

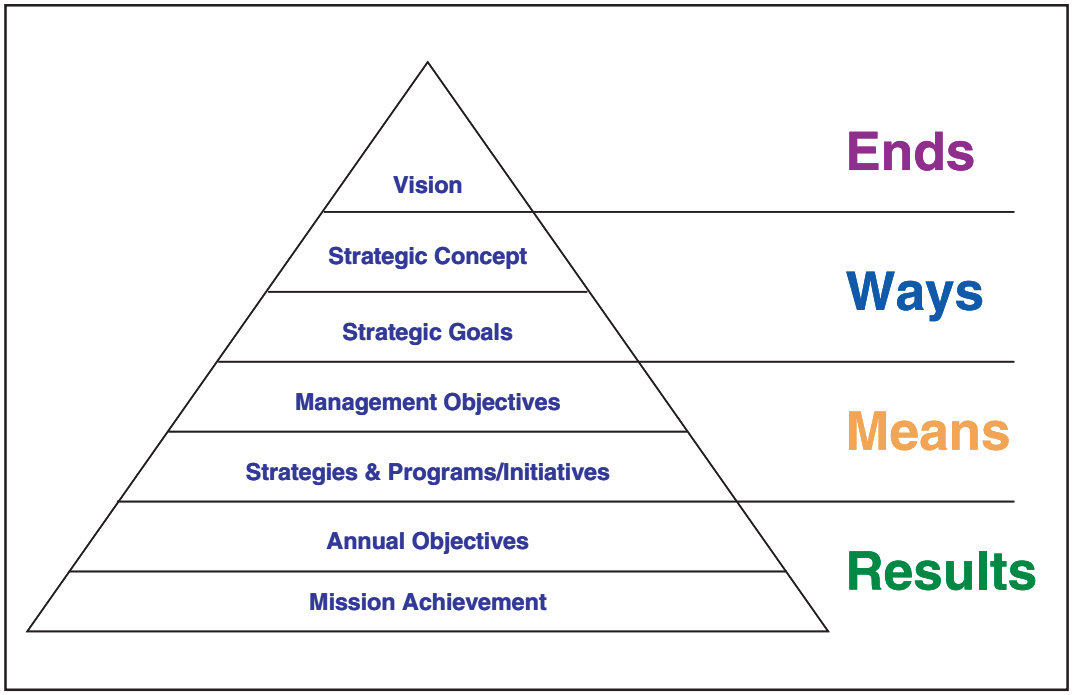


Figure 14. Logistics Transformation Framework—Linking Strategy to Measurable Results

We hope this endeavor will serve as a catalyst for an intellectual and professional resurgence in military logistics systems analysis. We are certainly encouraged by our empirical

research results which continue to reinforce and corroborate many of the intuitive concepts and ideas presented in this article. Consequently, we have engaged the larger military operations research and professional logistics communities and continue to encourage the participation of all those interested to collectively pursue this enormous challenge.

***Greg H. Parlier**, PhD, was the senior operations research/ systems analyst on active duty when he retired as an Army colonel. The project described in this article was initially undertaken in 2002 when he was assigned as Director for Transformation at the US Army Aviation and Missile Command, Redstone Arsenal, Alabama.*

Military Logistics and the Warfighter

I think we can all agree there is a relationship between the function of military logistics and the warfighter. What is that relationship, and is it correctly defined? In the early 1960s, there was a stated relationship between logistics and the weapons systems: military logistics "support" the weapons system. At that time, the subject of military logistics was fairly new and, with little ongoing research, very slow in providing greater *understanding* about it. Therefore, during that period, this definition of relationship seemed appropriate. It was not until the late 1970s that several advocates of military logistics came to the realization that logistics *support* of the weapon system was actually creating and sustaining warfighting capability. This warfighting capability was provided to the combat forces in the form of continuing availability of operational weapon systems (the tools of war). This new awareness set up another definition of the relationship: *military logistics creates and sustains warfighting capability.* While many heard the words, few realized their implications.

The level of warfighting capability that logistics provides the combat forces determines the extent to which war can be waged. This, in turn, limits and shapes how the war will be waged. Warfighting capability is *embedded* in the design of all weapon systems. Advancing technology increases speed, range, maneuverability, ceiling, and firepower, all of which provide more lethal and accurately guided munitions, stealth, and other offensive and defensive warfighting capabilities. They will be embedded into the design of future weapon systems. It is the weapon systems that contain the warfighting capability of military forces. The strength of military forces is no longer measured by the number of men *under arms*. Today, military forces are measured by the number—and warfighting capabilities—of their weapon systems. The Department of Defense has yet to adequately define and manage the total logistics environment (those activities and resources required to create and sustain warfighting capability). While it is said that armies travel on their stomachs, what is usually left unsaid is they perform on the basis of their logistics competency.

Today, as most of you are aware, we have another, more recently defined relationship: *military logistics supports the warfighter*. We know military logistics creates and sustains warfighting capability. We can assume the warfighter fights wars. It would, therefore, appear reasonable to suggest that in order for one to be a warfighter (a pilot in this case) he or she must have the capability to wage war. While weapon systems are designed and created to wage war, people are not. Therefore, in order to become warfighters, pilots must be provided with some level or amount of warfighting capability. I would submit that by providing the pilot with an operational weapon system, which allows him or her to utilize its warfighting capability, *military logistics creates the warfighter*. It does not *support* the warfighter; it *creates* the warfighter. This transformation occurs when a checked-out pilot starts the engine. At that point, the pilot is in control of the weapon system and its warfighting capability. The pilot is now the warfighter. Without the warfighting capability, which the weapons system provides, a pilot is a pilot.

Military logistics creates and sustains warfighting capability; by doing so, military logistics creates and sustains the warfighter.

Colonel Fred Gluck, USAF, Retired