A Lean Architecture for Transforming the Aerospace Maintenance, Repair and Overhaul Enterprise

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2005

International Journal of Productivity and Performance Management

Keywords: Enterprise Transformation
Classification: Conceptual Paper

The author would like to thank Mr. Timothy P. Cathcart and Mr. Mario Agripino of the Naval Undersea Warfare Center (NAVSEA), Newport, RI and Mr. Dennis J. Stamm of Lockwood Greene Engineering & Construction, Atlanta, Georgia, for their helpful contributions to this paper.

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Purpose

Increasing global competition, free trade agreements, low cost foreign labor, and customer expectations are causing manufacturing enterprises to implement aggressive transformation plans. Should these transformations be incremental or enterprise-wide? This paper addresses the question by developing a Lean Enterprise Architecture (LEA) concept for an enterprise-wide transformation.

Design/methodology/approach

The LEA is an Architectural Framework for Enterprise Reengineering in the design, construction, integration, and implementation of a Lean Enterprise using Systems Engineering Methods. The architecture uses a multiphase approach structured on the transformation life cycle phases.

Findings

Viewing Lean implementation across the entire enterprise minimizes the possibility of overlooking opportunities for further performance improvement. A silo view of Lean implementation may allow gaps in performance to persist, with no one assuming responsibility for the entire enterprise. Employing the principles of the LEA will help improve enterprise-wide quality, on-time delivery, and customer satisfaction by eliminating waste in the <u>entire</u> organization and supply chain.

Research limitations/implications

Applications and benefits are cited in the paper, but additional Case Studies are needed to benchmark the performance of the LEA against incremental Lean implementations.

Practical implications

The LEA was created for the U.S. military aerospace industry, but it is now being adopted in other commercial sectors for major transformation designs.

Originality/value

The LEA is the first known integration of Lean Thinking, Enterprise Architectures, and Systems Engineering principles in a design framework for the transformation of an enterprise.

1. Introduction

Consumer demands for a high degree of manufacturing responsiveness and reduced lead-times, unpredictability in the marketplace, resulting difficulties in forecasting, and pressures for reduced inventories are placing an increasing focus on the design efficiency of manufacturing systems and their supply chains (Matson 1998). In traditional manufacturing operations, the supporting facility infrastructure, equipment, processes, and personnel are operating with less-than-optimal flow processes, facility constraints, and outdated equipment. Traditional, or “Push”, manufacturing methods of production are batch-and-queue, task-oriented, and functionally isolated (Sharma 2001). Current systems are designed and arranged as separate system elements, which result in excessive inventory requirements and parts travel time and distance. Industrial processing equipment is aging and is at the point of needing refurbishment or replacement. Such systems are prone to excessive downtime due to long lead maintenance parts, out-of-business contractors, and obsolete parts. With over 60% of a total system’s life cycle cost associated with operations and maintenance, and as systems age, there is great opportunity to optimize the industrial space (Blanchard 1998).

The traditional industrial space needs to be improved to function at increased levels of efficiency through modern business philosophies and production techniques, such as Lean manufacturing (Lamming 1993, Womack 1996, Liker 1997, Maskell 2003). Lean manufacturing initiatives, based upon the famous Toyota Production System (Monden 1983, Ohno 1988, Shingo 1989), have been proven to produce excellent results when properly implemented. Lean manufacturing facilitates increased capacity, higher quality, and higher productivity while simultaneously reducing inventory and Order Lead Time (Kilpatrick 1997). How does an enterprise know if it is

Lean? Benchmarking oneself against best internal operations, or against external direct competitors, or against external functional best operations, or against generic functions regardless of industry, can be one measure of the relative value of one's leanness (Mathaisel 2004). Appropriately chosen metrics are used to assess whether or not an enterprise is Lean. There are no true established measures of categorical leanness, but Lean system introductions have been associated with time, space, quality, people, and cost savings. A recent Lean Aerospace Initiative study (MIT Lean Aerospace Initiative 2005) found:

- Labor hours: 10% to 71% improvement
- Costs: 11% to 50% improvement
- Productivity: 27% to 100% improvement
- Cycle time: 20% to 97% improvement
- Factory floor space: 25% to 81% improvement
- Travel distances (people or product): 42% to 95% improvement
- Inventory or Work in progress: 31% to 98% improvement
- Scrap, rework, defects or inspection: 20% to 80% improvement
- Set up time: 17% to 85% improvement
- Lead time: 16% to 50% improvement

Also very useful to the transformation of an industrial enterprise is a Cellular design (Sekine 1992, Levasseur 1995, Singh 1996, Mungwattana 2000). The integration of people, machines, and simplified control and manufacturing processes that bind them together within cells reduces costs, material scrap, manpower requirements, lead times, rework, flow times, and optimizes the use of floor space. The advantages derived from cellular manufacturing in comparison with traditional manufacturing systems in terms of system performance have been discussed in Askin (1993), Burbidge (1984), Collet (1995), Fry (1987), Howard (1993), Hyer (1989), Levasseur (1995), Singh (1996), and Wemmerlov (1989 and 1997).

In addition to such process improvement methodologies, manufacturers must confront the challenges with an aggressive architecture for the transformation of the complete enterprise. The transformation would entail changes in processes, material support, information systems, supplier relationships, organizational hierarchies, and management mindset. Thus, the architecture should portray the overall “flow” of the action phases necessary to initiate, sustain, and continuously refine the transformation (Brown 2000) that would result in the effective implementation of the Lean and/or Cellular principles and practices across the entire enterprise. The purpose of this paper is to describe the development of this architecture.

2. Definitions

Before describing the Lean Enterprise Architecture, and to put the architecture in context with other approaches, some definitions are needed.

- A Lean Enterprise is “an integrated entity that efficiently creates value for its multiple stakeholders by employing lean principles and practices” (Nightingale 1999).
- Systems Engineering is “an interdisciplinary approach and means to enable the realization of successful systems” (IEEE 1998).
- Enterprise Engineering is the “collection of tools and methods which one can use to design and continually maintain an integrated state of the enterprise” (ISO WD 15704).
- Systems Engineering Methods are the “logical systematic set of processes selectively used to accomplish systems engineering tasks” (IEEE 1998).
- Systems Architecture is the “arrangement of elements, subsystems, and the allocation of functions to meet systems requirements” (IEEE 1998).
- Systems Architecting is the “art and science of creating and building complex systems” (Rechtin 2000).
- Organizational Architecting “is the application of systems architecting to organizations” (Rechtin 1999).
- An Architecture Framework describes “basic concepts, descriptions, and the related models (views) to provide a standard for enterprise engineering” (IEEE P1471).

The Lean Enterprise Architecture (LEA) is an Architectural Framework for Enterprise Reengineering in the design, construction, integration, and implementation of a Lean Enterprise using Systems Engineering Methods. LEA was developed for the U.S. military aerospace maintenance, repair and overhaul (MRO) industry. The industry is in need of a complete redesign and reconstruction, and to do so it requires an architecture for the transformation. In searching for an architecture (Kaiser-Arnett 2003), the industry did not want a Design-Build[1] approach (Pearce 2005), as is commonly employed in the construction industry, or a Kaizen Blitz approach[2] (Laraia 1999), often used in Lean manufacturing implementations. There are significant differences between these methods and the LEA and their impact on the organization that is undergoing the transformation process. The Design-Build method is very conducive for enterprises who prefer to move quickly on a transformation and desire a single point of responsibility for both the design and the construction of the project. The most significant driving factor is the schedule. The transformation moves rapidly, and one must make decisions quickly. The Kaisen Blitz approach attempts to capture the "low hanging fruit" by first leaning out waste in existing systems through the use of value stream mapping (Tapping 2002) and kaizen events (Imai 1986). The process continues until all cells have been leaned-out, at which time they are balanced and then integrated so that the system is "pull-based", pulling the requirements from the customer, rather than pushing the requirements onto the customer. Often, Lean success is defined as the existence of a "kaizen culture" in which lean tools are effectively applied, by enthusiastic employees, to eliminate waste every day. "If this is true, then many organizations should probably quit their lean programs now, as they will never succeed by this definition. There is no roadmap for achieving a kaizen culture, and left to their own devices,

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[1] Design-Build, a "buzz word" from the 1980s, is a fast-track building approach that evolved from the master builder concept of more than a hundred years ago. It is a delivery system for a construction project with strict scheduling demands, complex design issues, and a carefully controlled construction environment.

[2] Kaizen Blitz is "a sudden overpowering effort to take something apart and put it back together in a better way", Dave Nave, modified by J. Keith Shiveley, ISIXSIGMA, Sep. 22, 2003.

most organizations will run out of time and patience before they discover the path" (Roper 2005).

The design of the LEA incorporates Lean attributes and values as baseline requirements for the re-creation of the enterprise. The approach is a structured systems engineering method for a Lean enterprise transformation. The LEA architecture is meant to be complimentary with Lean and other continuous improvement processes, such as Total Productive Maintenance (TPM) (Nakajima 1988, Robinson 1995, Leflar 2001). TPM focuses on the optimization of equipment and process productivity, and Lean Manufacturing addresses the elimination of waste (labor, time, cost, inventory, etc.) while establishing customer-driven (pull), Just-In-Time (JIT) production. The LEA architecture uses a multiphase Lean approach structured on the transformation life cycle phases and is developed from an enterprise perspective, paying particular attention to strategic issues, internal and external relations with all key stakeholders, and structural issues, such as TPM, that must be addressed before and during a significant change initiative. The LEA architecture will now be presented.

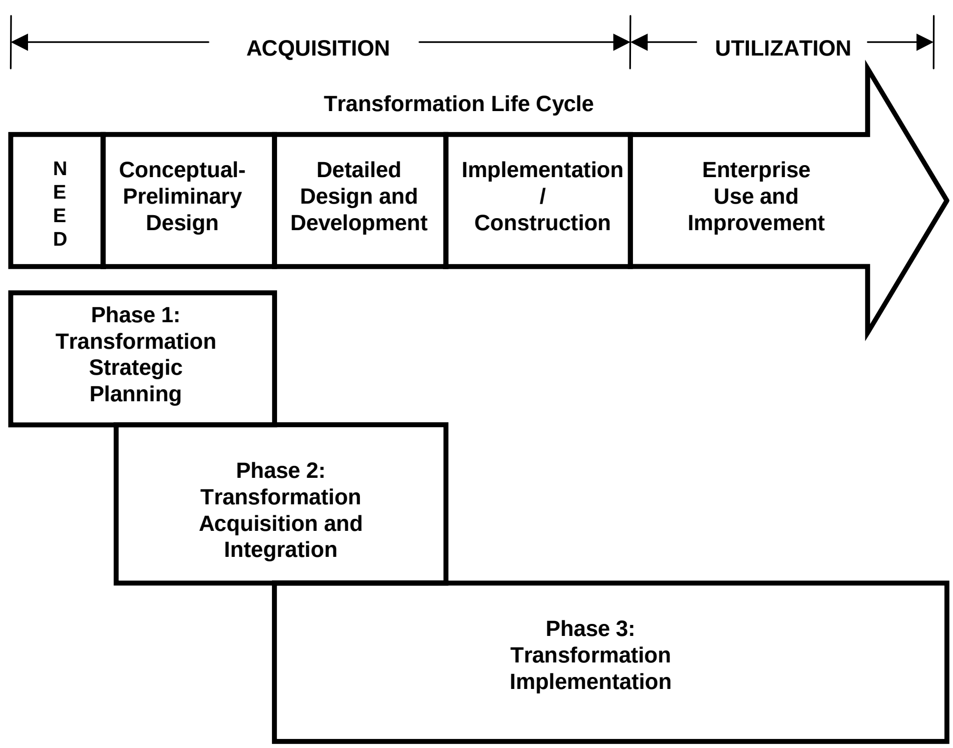
3. The Lean Enterprise Architecture (LEA): a Methodology for Enterprise Transformation

In order to effect a successful transformation, manufacturers require an integrated set of activities and support documents that execute their strategic vision, program concepts, acquisition strategy, schedule, communications plan, and implementation strategy. To this end, the authors created the Lean Enterprise Architecture (presented in Figure 1). LEA is a structure to organize these activities for the transformation of the enterprise from a current state to a desired future Lean condition. The LEA uses a phased approach structured on the life cycle of the transformation. It portrays the flow of phases necessary to initiate, sustain, and continuously refine an enterprise based upon Lean principles and systems engineering methods.

The top of the illustration in Figure 1 represents the life cycle of the transformation. The bottom of the illustration represents the architecture that is used to create the life cycle. The architecture is comprised of three phases (shown at the bottom of the illustration).

1. The first component is the Transformation Strategic Planning phase, which specifies the actions associated with the decision to adopt the Lean paradigm.
2. The second component is the Transformation Acquisition and Integration phase, in which the environment and conditions necessary for a successful change in the enterprise are created.
3. The organization is then prepared for the launch into detailed planning and implementation, which is the third phase, the Transformation Implementation phase, where the transformation of the enterprise is planned, executed, and monitored.

Figure 1
Lean Enterprise Architecture Phases



Each phase in this architecture creates the conditions necessary to successfully progress through the life cycle of the transformation. The description of each component of the life cycle is given in Table 1.

Table 1 **Transformation Life Cycle Components**	
Component	**Description**
Need	Wants or Desires for transformation of the enterprise, because of obvious deficiencies or problems.
Conceptual and Detailed Design	Market analysis, feasibility study, requirements analysis, enterprise system design and development, simulation, engineering prototyping, benchmarking, acquisition plans, trade-off analysis, and specifications development.
Implementation / Construction	Modify, procure, integrate, install, test, train, and implement the transformation of facilities, production systems, business systems, and policies.
Enterprise Use and Improvement	Operational use of the transformation, and continued review for improvement or modification.

Since the five principles of Lean Thinking (Womack 1996) is an important ingredient to the architecture, links can be drawn between the components of the framework and the existing Lean tools and techniques. These relationships are identified in Table 1 and further described in Table 2.

Table 2 **Relationship between the LEA and the Five Principles of Lean Thinking**		
Component	**Relationship to the Five Principles of Lean Thinking**	**Discussion**
Need	(1) Value	Every enterprise needs to understand what *value* the customer places upon their products and services. The **Need** for the transformation is to eliminate waste and cost from the business

		process so that the transformation can be achieved at great value to the enterprise and its customers. Value is achieved through the use of the quality tools and continuous process improvement techniques espoused by Shewart (1989) (the Plan, Do, Study, Act cycle), Demming (1986) (Total Quality Management), Harry and Schroeder (2000) (Six Sigma), and many others.
Conceptual and Detailed Design	(2) The Value Stream and (3) Flow	The *value stream* is the flow of a product's life-cycle from the origin of the raw materials used to make the product through to the customer's use and ultimate disposal of the product. In the **Conceptual and Detailed Design** component of transforming the enterprise, it is only through a study of the value stream and its value-added or waste, using techniques like Value Stream Mapping (Tapping et al, 2002), can an enterprise truly understand the manufacturing process and/or service. Lean thinking advocates supplier and customer partnerships and radical supply chain management to eliminate waste from the entire value stream. One very significant key to the elimination of waste is *flow*. If the value chain stops moving forward for any reason, waste can occur. The principle of the transformation design is to create a value-stream where the product, and its raw materials, components, and sub-assemblies, never stop in the production process, and where each aspect of production and delivery is fully synchronized with the other elements. Carefully designed flow across the entire value chain will tend to minimize waste and increase value.
Implementation / Construction	(4) Pull	During **implementation**, the way to ensure that nothing is made ahead of time and builds up work-in-process inventory that stops the synchronized flow is to use a *pull* approach. A traditional western manufacturer will use a Materials Requirements Planning (MRP) or Enterprise Resource Planning (ERP) style of production planning and control, whereby production is "pushed" through the factory based upon a forecast and a schedule. A pull approach states: do not make anything until the customer orders it. To achieve this requires great flexibility and very short clock speeds (Fine 1998) in the design, production, and delivery of the products and services. It also requires a mechanism for informing each step in the value chain what is required of them today, based upon meeting the customer's needs.
Enterprise Use and Improvement	(5) Perfection	A lean enterprise sets its target for **improvement**. The idea of *Total Quality Management* (Deming 1986) is to systematically and continuously remove the root causes of poor quality from the production processes, so that the plant and its products are moving towards perfection. This relentless pursuit of perfection is a key component in the transformation of an organization that is "striving for lean".

In the discussion that follows, the authors further describe the essential steps and documents that accompany each phase of the Lean Enterprise Architecture. These steps and documents are necessary to initiate, sustain, and continuously refine an enterprise transformation that would result in the implementation of the Lean principles.

3.1 Phase 1: Transformation Strategic Planning

Best practices continue to demonstrate the benefits of a Strategic Plan to focus the effort and energy of an organization toward the achievement of common goals, objectives, and performance metrics. Thus, the first step in a transformation acquisition is to develop a Strategic Plan. The success of the organization is highly dependent upon a focused vision set forth in a carefully conceived plan. The strategic plan should encompass the three crucial change elements of the transformation process: Infrastructure, Lean operations, and Personnel Change Management. The Strategic Plan is a key part of Phase 1 of the LEA. Phase 1 must also include the development of a high-level enterprise concept of operations that specifies the operating philosophy and forces discussion and planning to determine how the manufacturing processes will operate on a day-to-day basis.

3.2 Phase 2: Transformation Acquisition and Integration

Transformation acquisition necessitates the development of a Requirements Package, an Acquisition Plan, an Integration Plan, and a Change Management and Communication Plan.

3.2.1 Requirements Package

The Requirements Package consists of a Statement of Objectives or Statement of Work (SOO/SOW) for the transformation, its scope and specifications, a Contract Data Requirements List (CDRL) with acceptance criteria, and a delivery schedule. The package addresses the need for urgent cultural transformation and identifies the need for IT integration. The package should also include a requirement to demonstrate and defend the expected return on investment of the transformation against established performance metrics.

3.2.2 Acquisition Plan

An Acquisition Plan outlines the strategy for managing the acquisition elements of the transformation. Contracting methods can include turnkey, program manager, design/purchase/construct, design/construction management, or some variation of these common contracting methods. Selection of the contracting method is influenced by the experience and availability of internal resources. Selection of a Program Mananger, or of a turnkey transformation contractor, should include early and continuous involvement of suppliers including engineering services, equipment providers, IT system suppliers, integrators, consulting services and contractors. Supplier selection should place emphasis on past performance, performance-based requirements, oral presentations, cost/benefit analysis, capital spending scheduling, and full and open competition and briefings. The plan must also identify the risks associated with the transformation and develop a mitigation strategy to overcome them.

3.2.3 Integration Plan

Phase 2 of the LEA also includes an Integration Plan. Integration encompasses an approach to establishing the appropriate lines of communication: vertically, for those stakeholders directly involved in the implementation of the transformation; and horizontally, to consider the impacts of other productivity enhancement initiatives (e.g., information system upgrades, contract repair financial/operational changes, supply support). The plan needs to consider how the transformation will affect, and be affected by, other initiatives. It may require a collaborative software tool to enhance communications, review, decision-making, and actions taken throughout the affected organizations. The Integrated Process and Product Development (IPPD) approach is an example of one commercially proven tool that can help the transformation achieve its goals more efficiently and effectively by focusing on the integration and application of critical activities early on in the acquisition process. Two key pillars of the IPPD are the Integrated Master Plan (IMP) and Integrated Master Schedule (IMS). Together, these management tools provide the integrated plan of events and activities, the schedule in which these will occur, and the resources that will be used to execute them.

3.2.4 Change Management and Communications Plan

Phase 2 also requires a Change Management Plan (Table 3). The heart of change management is communication. However, that communication is effective only when it is focused in the context of an overall change management plan. Therefore, the scope should extend across all areas of change management, including strategy, training, and supporting management systems (Synergy 2003). A successful Lean transformation depends, in large part, upon how effectively management communicates with those affected by the transformation. This communication must address, at a minimum, what's happening, why it's happening, and how it's happening. More importantly, each individual and organization affected by the transformation must understand how the transformation impacts him or her.

Included in a change management/communications plan should be the development and maintenance of a website to include briefings, presentations, contact lists, milestones, mission statement, organizational goals, streaming video shows, collaborative tools, and other communication tools.

Table 3

The Change Management and Communications Plan (Kotter 1996)

- Establish The Motivation For Change And A Sense Of Urgency
- Train
- Build A Guiding Coalition
- Develop A Vision And Strategy For Change
- Communicate The Vision
- Empower Broad-Based Action
- Generate Short-Term Wins
- Sustain The Momentum: Consolidate Gains And Produce More Change
- Anchor New Approaches in the Culture

3.3 Phase 3: Transformation Implementation

Transformation implementation is built on a strong centralized vision, continuous improvement, and progress measurement. Successful implementation also requires leadership, innovation, and organization. That basic leadership and organizational framework occurs when the necessary personnel are versed in program management, best Lean and/or Cellular manufacturing processes, financial management, acquisition, source/vendor selection, administrative/office support, and other functions that are deemed necessary to help integrate company and general contractor personnel efforts.

Thus, a good implementation plan is one of: monitoring schedules, performance metrics, and engineering changes; managing risks, costs, and vendor selection; prioritizing payback initiatives and resources; and fostering a sense of urgency in task completion (Table 4).

Table 4

The Transformation Implementation Plan

- Monitor schedules and performance
- Manage risk
- Source selection planning
- Prioritize (and obtain funding for) the highest payback initiatives (measure and ensure ROI)
- Provide program/budget guidance and defend resources
- Implement and monitor the difficult task of embedding cultural change within the depot.
- Foster a sense of urgency for task completion coupled with a commitment of time and resources and establish metrics that drive the proper behavior

4. The Role of Systems Engineering in the Lean Enterprise Architecture

LEA is an enterprise-wide structure rooted in the concepts of systems engineering. To demonstrate how the management tools of Lean and the technical tools of systems engineering work together within the phases of the LEA to ensure an effective transformation, the concept of "Lean Enterprise Transformation Engineering" needs to be defined. In Section 3 of this paper, Enterprise Engineering was the "collection of tools and methods which one can use to design and continually maintain an integrated state of the enterprise" (ISO WD 15704). Based on this definition, Lean Enterprise Transformation Engineering is defined to be a discipline that uses the tools of systems engineering and the management practices of Lean to organize all of the tasks needed to design, implement, and operate enterprise transformation change. The structure for the transformation is based on the life cycle of the enterprise. The military and commercial Maintenance, Repair, and Overhaul (MRO) enterprises, as well as their products, follows this life cycle. The cycle begins with the initial concept for a system or transformation and then proceeds with development, design, construction, operation and maintenance, refurbishment or obsolescence, and final disposal of the system (Blanchard 1998). Understanding this life cycle is key to an understanding of the architecture presented here. An excellent reference for a more detailed description of the life cycle of an enterprise is the GERA (Generalized Enterprise Reference Architecture) framework that was developed by an IFIP-IFAC (International Federation for Information Processing – International Federation of Automatic Control) Task Force (Bernus 1998).

Lean Enterprise Transformation Engineering uses an Architecture Framework to define and describe enterprise design and implementation solutions. Architecture Frameworks describe basic concepts, descriptions and the related models (views) to provide a standard for enterprise engineering (IEEE P1471 1998). There are four basic Enterprise Engineering frameworks:

a. Computer-Integrated Manufacturing Open System Architecture (CIMOSA) (Bernus 1995)
b. Generalized Reference Architecture and Methodology (GERAM) (Bernus 1998)
c. GRAI Laboratory Model (GRAI/GIM) (Doumeingts 1987 and 1992)
d. Purdue Enterprise Reference Architecture (PERA) (Purdue 1989)

Of these four, the Generalized Reference Architecture and Methodology (GERAM) framework was selected by the authors and adapted as the Lean Enterprise Transformation Engineering framework for the LEA architecture. The framework is shown in Figure 2. The reason for adapting the GERAM framework was because of its "recognition of the life-cycle life-history differentiation, allowing the representation of multiple change processes, and allowing the representation and characterization of various methodologies, according to their typical life-history patterns (such as top-down, bottom-up, inside-out, spiral, total re-engineering, incremental change - kaizen, concurrent engineering, etc.)" (Bernus 1998). The framework provides a description of all elements required in enterprise engineering and integration. It is intended to facilitate the unification of several disciplines in the change process, such as industrial engineering, management science, control engineering, communication, and information technology, to allow their combined use in the design process. It is structured using an enterprise life cycle perspective that compliments and integrates with the LEA transformation lifecycle phases. Lean/Cellular transformation practices and methods are incorporated into the framework as design requirements for the future state enterprise. System engineering and enterprise engineering methods coupled with the framework will be used to design, develop, test, evaluate, integrate and implement the Lean enterprise transformation.

How would an enterprise use the LEA framework for its Lean transformation? As illustrated in Figure 2, there are five fundamental tasks that should be followed: conceptual design, preliminary design, detailed design, implementation, and operation. Each of these tasks is detailed in Table 5. The tasks are sequential; they follow the fundamental principles of systems engineering; and they are based on the life cycle of the enterprise. Specified within each task (and listed in Figure 2) is the collection of process improvement tools and methods that one can use to design and continually maintain a Lean state of the enterprise.

Figure 2
Lean Enterprise Transformation Engineering
(Apapted from Blanchard & Fabrycky (1998), p.26)

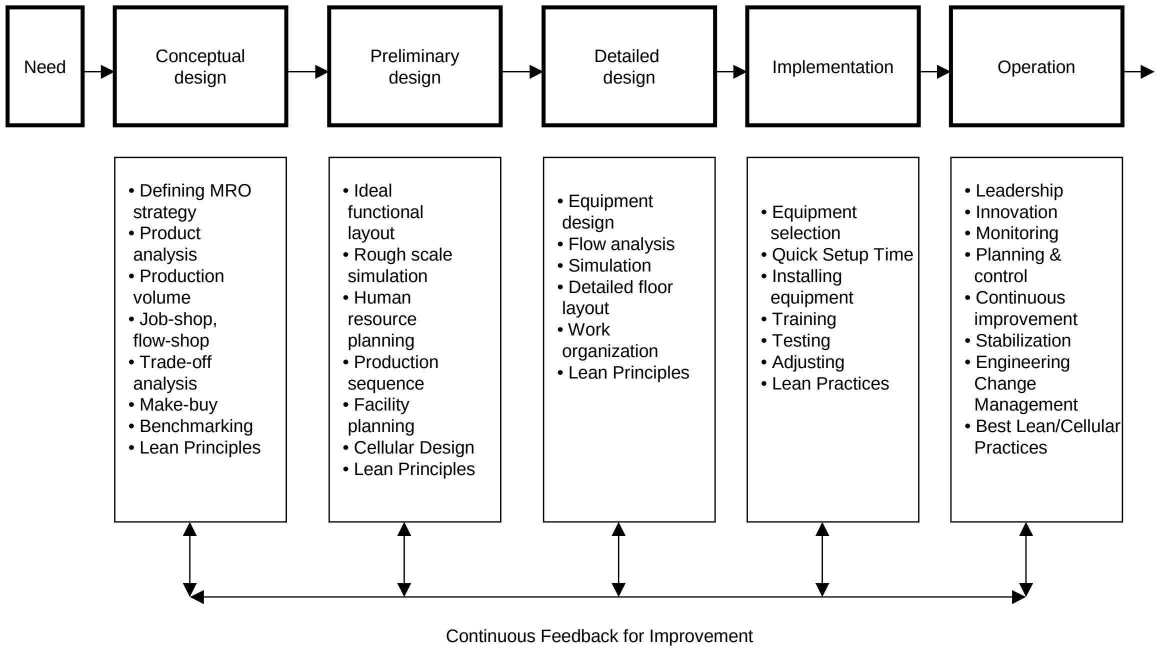


Table 5
Description of the Five Basic Tasks in the Lean Enterprise Transformation Engineering Framework

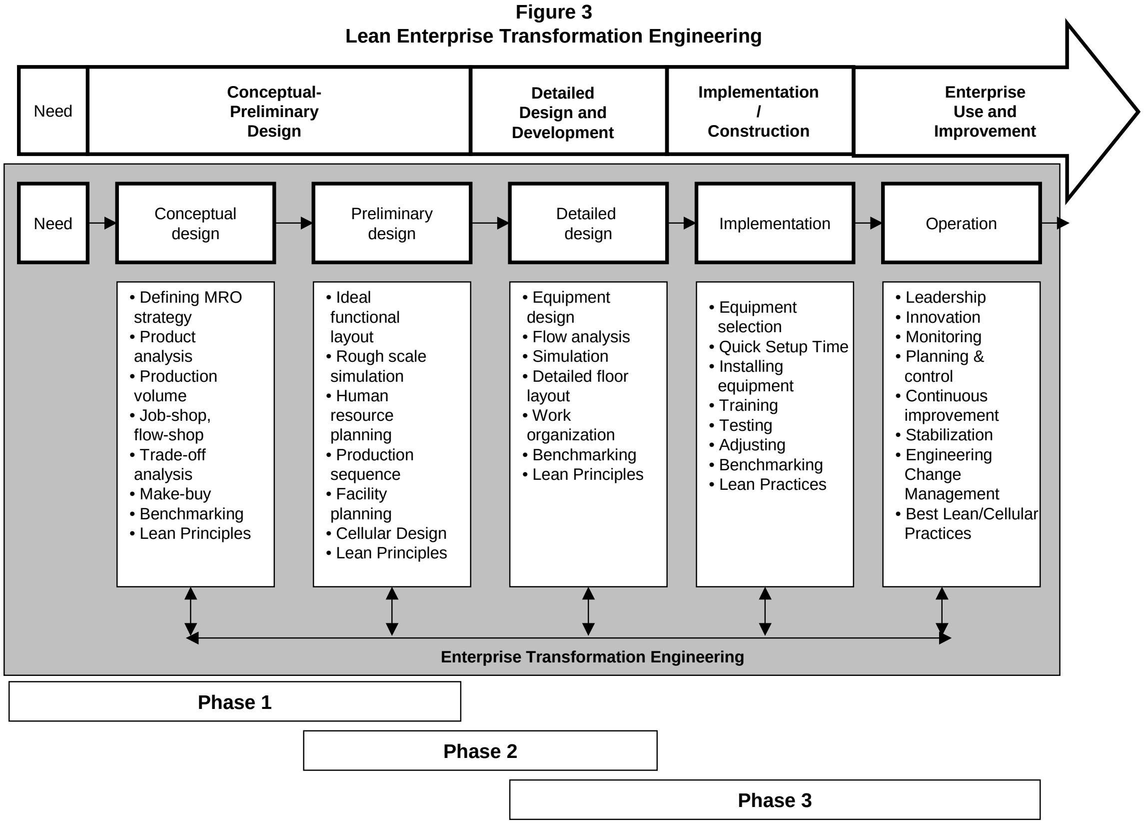
Task	Description
Conceptual Design Task	For the Conceptual Design task, the strategic position of the enterprise is evaluated for competitive capability, organizational structure, and the processes. Current business strategies and market research are used to define future state enterprise architecture performance requirements. Feasibility studies, formal business case analysis, and return on investment projections are used to select a conceptual architecture for the enterprise from various configuration alternatives. The conceptual enterprise architecture defines a concept of operations for future state enterprise performance, organizational and value chain structures, technology, human resources, facilities, products, and operational requirements. The architecture defines operational interfaces and performance requirements to meet enterprise business strategy, vision, and mission objectives.
Preliminary and Detailed Design Tasks	During these tasks, the conceptual architecture is evaluated and synthesized into functional and operational architectures. The functional architecture is developed during the preliminary design to describe enterprise functional and performance requirements. The operational architecture is developed during the detailed design task to describe the enterprise organizational structures and their individual configurations (organization structures, technology, human resources, facilities,

	products, etc,). System engineering methods are used to design and develop these architectures using integrated product teams (IPTs). Each level of the architecture captures a stage in the design process as more detail evolves. The IPT's perform systems engineering analysis from previous architecture definitions and use trade studies to select architectural components. The architecture forces the IPTs to maintain a total enterprise solution that properly aligns processes and organizational components. This approach provides an enterprise engineering method to meet organizational requirements. During the design tasks, facility and production system cells are designed in accordance with Lean principles.
Implementation Task	During this task, the operational architecture is produced and implemented using structured project management methods. The operational architecture is used to develop the enterprise transformation plan. The plan will describe all tasks necessary to implement the future vision. During the implementation task, facility and production system cells are constructed and modified in accordance with Lean practices. Specialized equipment and selected IT networks are procured, installed, integrated, tested, and certified. Work force training is conducted for new enterprise operations. Implementation can be either incremental or a one time event depending on risk. Implementation requires significant integration of people, technology, facilities, and operational processes. During this phase, great care must be given to prevent disruption to current operations while simultaneously implementing enterprise changes. Implementation must consider both internal and external architecture interfaces.
Operation Task	The operation of the transformed facilities and production system cells should ensure the continued strong centralized vision, transformation improvement goals, and progress measurement metrics that were designed in the earlier tasks of Phases 1 and 2. All of the hard work in the tasks leading up to this point should not be in vain. The enterprise architecture is only as good as the leadership, organization, and engineering frameworks that are the foundation of the architecture. Thus, transformation operation requires continuous leadership, innovation, monitoring, control, and management of engineering changes. Such changes require a complete risk, impact and cost assessment to either the production system or entire enterprise. In addition, any operations that undergoes transformation operates best when all personnel are versed in the most current best commercial Lean and/or Cellular manufacturing principles and practices.

5. Putting It All Together: Enterprise Transformation Engineering and the LEA

Figure 3 shows how the Lean Enterprise Architecture and the concepts of Lean Enterprise Transformation Engineering work together to ensure an effective and successful transformation of the enterprise. The top of the illustration in Figure 3 represents the life cycle of the transformation. The bottom of the illustration represents the three phases of the LEA. Each phase in the architecture creates the conditions necessary to put into effect the life cycle of the transformation. The middle of Figure 3 (shaded region) is the framework for the Lean Enterprise Transformation Engineering. This combination of Lean and systems engineering methodologies portrays the overall flow of the action steps necessary to initiate, transform, sustain, and continuously refine an enterprise.

Figure 3
Lean Enterprise Transformation Engineering



6. Applications, Use, and Reasons Why an Enterprise-Wide Architecture is So Important

Although the Lean Enterprise Architecture was developed for the U.S. military aerospace maintenance, repair and overhaul (MRO) industry, it is beginning to appear in other U.S.

commercial and military manufacturing implementations. Table 6 summarizes some of the known applications.

Table 6
Commercial and Military Applications of the LEA

Application	Institution Performing the Application	Description
Commercial	Lockwood Greene Engineers, Inc. (Lockwood Greene 2005)	1. Customer: PACCAR (Kenworth and Peterbilt Trucks) 2. Period of Performance: December 1997 to Present 3. Contract Value: $5,109,749 4. Brief Description: PACCAR's Lean Transformation Program is a multi-year effort involving their world-wide truck manufacturing complex. The lean transformation program is being executed by phases by plant site in several different North America and central Europe countries. This is a production program involving program management services, lean manufacturing analyses, cellular designs, production equipment assessments, extensive facility modification design packages, and construction phase support services at multiple production plant sites in North America and central Europe.
Commercial	Lockwood Greene Engineers, Inc. (Lockwood Greene 2005)	1. Customer: Thomson Multimedia, Inc. 2. Period of Performance: June 2001 through April 2003 3. Contract Value: $10,322,382 4. Brief Description: This was a production project involving Program Management; lean manufacturing analyses and design; production equipment condition assessment (over 5300 pieces of equipment); equipment relocation and installation design packages; on-site construction management; and start up services. Conducted a fast-paced Lean Manufacturing analyses (Visioneering) seminar to gain consensus on facility concepts. Redesigned process flow line to accommodate existing and new equipment in a lean flow through process in new facility as opposed to departmental process from old facility. Performed detailed condition assessment on approximately 55 manufacturing systems comprised of approximately 5,300 individual pieces of equipment to determine if manufacturing equipment should be transferred, refurbished, stored or scrapped. Developed 94 detailed engineering layout drawings for all manufacturing areas for new picture tube assembly line. Generated detailed performance and technical specifications for major equipment procurement or refurbishment. Generated cost savings and cost avoidances to the to the client totaling over $9M dollars including over $400K in annual recurring energy savings.
Commercial	Lockwood Greene Engineers, Inc.	1. Customer: US Mint 2. Period of Performance: October 2002 to Present

	(Lockwood Greene 2005)	3. Contract Value: $1,531,000 4. Brief Description: This is a production transformation involving program management services, lean manufacturing analyses, process modeling, lean/cellular designs, production equipment assessments, manpower planning, facility modification design packages, and eventual construction phase support services at multiple US Mint plant sites in America.
Military Maintenance, Repair and Overhaul Depot	U.S. Air Force, Oklahoma City, Air Logistics Center (OC-ALC) (Source: OC-ALC/MA-T Solicitation #FA8100-04-R-0001)	1. Customer: U.S. Air Force, Air Force Materiel Command 2. Period of Performance: 2005 - 2015 3. Contract Value: $500,000,000 4. Brief Description: The scope of the Oklahoma City Air Logistics Center (OC-ALC) Maintenance, Repair and Overhaul (MRO) Transformation Program is to design, develop, construct, install, implement and deliver a dramatically improved maintenance, repair and overhaul processes within existing facilities. The program will address a Lean and Cellular (hereafter referred to as "Lean/Cellular") transformation of the MRO system for aircraft, engines, commodities, and weapon system software. OC-ALC/MA-T adopted the Lean Enterprise Architecture (LEA) (Agripino et al, 2005) strategy to transform the ALC industrial enterprise.
Military Maintenance, Repair and Overhaul Depot	U.S. Air Force, Ogden, Utah, Air Logistics Center (OO-ALC) (Source: OO-ALC/MA-T Solicitation #FA8201-04-R-0017)	1. Customer: U.S. Air Force, Air Force Materiel Command 2. Period of Performance: 2005 - 2010 3. Contract Value: $37,500,000 4. Brief Description: The program objectives for this transformation effort are to design, develop, construct, install, implement and deliver a dramatically improved maintenance repair and overhaul (MRO) process and facilities. The program will address a lean/cellular transformation of MRO for aircraft landing gear, wheels and brakes. Commodities will be addressed as they impact landing gear refurbishment production operations or as stand alone business units as they are disrupted in the transformation process. This program is necessary to meet the OO-ALC objective of affordable increased throughput. OO-ALC adopted the Lean Enterprise Architecture (LEA) (Agripino et al, 2005) strategy to transform the ALC industrial enterprise.

These applications have chosen to take an enterprise-wide approach to their Lean implementations. Why? Viewing Lean implementation across the entire enterprise minimizes the possibility of overlooking opportunities for further performance improvement. A silo view of Lean implementation may allow gaps in performance to persist, with no one assuming responsibility for the entire enterprise (DEMEP 2004). Employing the principles of the LEA will help improve enterprise-wide quality, on-time delivery, and customer satisfaction by eliminating waste in the <u>entire</u> organization and supply chain. In turn, this helps drive operating costs to where they make a difference to the Return on Investment (ROI), and to minimize costs that don't. The Delaware Manufacturing Extension Partnership (DEMEP 2004) cites the following benefits:

- **Improved Quality** - Quickly identifying potential problems and addressing them early in the process minimizes rework and improves the overall quality of the end product. MRO enterprises can typically reduce defects by at least 20% per year and improve quality by up to 85%.
- **Increased Productivity** - Lean techniques allow an enterprise to produce more with existing resources by eliminating non-value-adding activities. MRO enterprises can increase productivity by up to 30% per year.
- **Enhanced Customer Satisfaction** - Lean MRO enterprises deliver the quality products customers demand - on time, every time. The military can enhance customer satisfaction by reducing lead times by up to 90% and increasing "on time delivery" to almost 100%.
- **Reduced Operating Costs** - By improving quality, productivity, and customer satisfaction, Lean military MRO enterprises can substantially reduce operating costs. For example, by eliminating or streamlining work processes, the military can reduce inventory more than 75%.

Furthermore, according to the National Institute of Standards and Technology (NIST), an enterprise-wide Lean transformation can lead to the productivity improvements shown in Table 7.

Table 7
Percent of Benefits Achieved Through
Enterprise-Wide Lean Transformation

(Source: Source: Karl H. Schultz, Lean Management, Lean Results, www.leanscm.net)

Space Utilization	80%
Quality Improvements	90%
WIP Reduction	95%
Productivity Increase	55%
Lead Time Reduction	90%

Many North American manufacturers, eager for instant results, try to steal the "quick fix" parts of lean and awkwardly force them into their existing plants to attack the enemy: waste. Here's what the enemy, "Muda", looks like (MIT Lean Aerospace Initiative 2005):

- Overproduction: to produce more than demanded or produce it before it is needed. It is visible as storage of material. It is the result of producing to speculative demand.
- Inventory or Work In Process (WIP): is material between operations due to large lot production or processes with long cycle times.
- Transportation: does not add any value to the product. Instead of improving the transportation, it should be minimized or eliminated (e.g. forming cells).
- Processing waste: should be minimized by asking why a specific processing step is needed and why a specific product is produced. All unnecessary processing steps should be eliminated.
- Motion: of the workers, machines, and transport (e.g. due to the inappropriate location of tools and parts) is waste. Instead of automating wasted motion, the operation itself should be improved.
- Waiting: for a machine to process should be eliminated. The principle is to maximize the utilization/efficiency of the worker instead of maximizing the utilization of the machines.
- Making defective products: is pure waste. Prevent the occurrence of defects instead of finding and repairing defects.

To eliminate Muda, manufacturers turn to the "quick fix" lean tool that is increasingly popular, the Kaizen Blitz (Laraia 1999), which is a team set up to attack these wastes and inefficiencies in one element of a manufacturing process, not the entire enterprise. Kaizen means "incremental improvement". But experts caution that stealing bits and pieces of lean, and performing an incremental implementation, isn't enough (Phillips 2000). "You will never Kaizen your way to lean."[3]. Even someone who took part in more than 200 Kaizen Blitzes says it is tough to make the gains stick:

[3] Thomas Jackson, Productivity Inc., www.productivityinc.com, as reported in "Building the Lean Machine," (Phillips 2000).

> “Kaizen is a good catalyst for change, but it won't sustain a major cultural change. It's problem is its rapidity. In the long-run, only simple solutions sustain. It's easy to say - hard to make happen.” (Laraia 1999)

Members of various other service companies involved in recent lean implementations have made similar public comments that identified “incremental Lean” as one of the causes of their firm's Lean implementation breakdowns. The bifurcation of Lean implementation within the firm meant that no one had the 25,000-foot view of what was happening across the enterprise; and this led to internal control shortcomings that were not identified (Bies 2004).

7. Conclusions and Future Directions

Manufacturing operations must improve operational and financial performance to avoid potential downsizing or reduction of its infrastructure. The most efficient and effective method of supporting transformation is conversion to process improvement (such as Lean, Total Productive Maintenance, and Cellular manufacturing) philosophies and processes. Failure to provide needed levels of support will result in unresponsive, inefficient enterprise operations. This, in turn, increases material costs and decreases the competitiveness of the business. That poor performance has a direct impact on product quality, performance and cost. Changing the traditional command and control organizational structure is necessary. Several elements are essential to the successful implementation of enterprise-wide Lean implementation. One is clearly articulated enterprise-wide goals and metrics that provide a foundation for the Lean implementation program. A second is Lean training and communication across the enterprise, which is critical because it enables individuals throughout the organization to conduct meaningful cross-functional discussions about Lean. A third element is that the implementation is enterprise-wide, not incremental in one element or cell of the manufacturing process. In addition to such process improvement methodologies, manufacturers must confront the challenges with an aggressive architecture for the transformation of the complete enterprise.

In this paper, the authors have developed a Lean Enterprise Architecture (LEA) that uses Lean enterprise and systems engineering methodologies to portray the overall flow of the action steps necessary to initiate, sustain, and continuously refine the entire enterprise. The architecture was developed from an enterprise perspective, paying particular attention to strategic issues, internal and external relations with all key stakeholders, and structural issues that must be addressed before and during a significant change initiative. In today's environment, organizations that are considering a transformation to Lean should embrace an enterprise-wide architecture.

What is the next step in this research agenda? The authors are now developing a more specific process for the LEA that is intended to further define the performance requirements (improvement metrics), systems engineering processes, and architectural details that are necessary for a successful implementation, integration, and validation of the framework. The process needs to integrate all of the elements of an enterprise (its business systems, facilities, logistic networks, transportation systems, strategic business units, cells and other functional workspaces, and the workforce) in order to meet the strategic objectives of a Lean implementation across the entire enterprise. Specific future research tasks are to:

1. Continue to research existing architectural standards and frameworks, like the PERA (Purdue 1989) and GERAM (Bernus 1998) architectures, for their applicability to the LEA design
2. Review current system engineering processes
3. Examine how architectural frameworks can be used in the system engineering process
4. Refine the design and details of the LEA to conform to these processes and frameworks
5. Through case studies, benchmark the performance of the LEA and its processes against other Lean implementations

6. Design an implementation roadmap for those enterprises that wish to undertake an LEA transformation

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