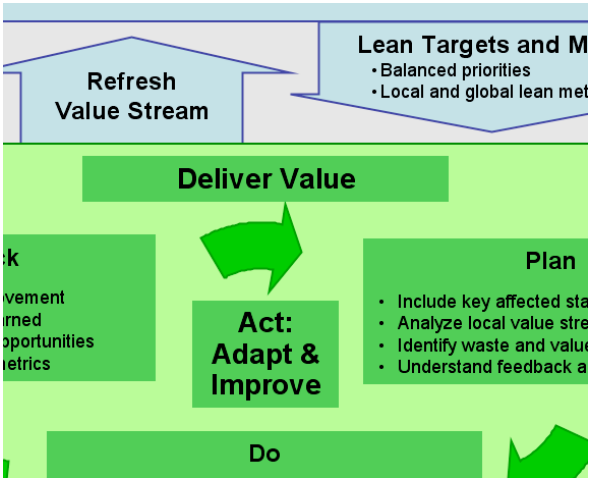
Product Development Transistion to Lean (PDTTL) Roadmap



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Hugh L. McManus, PhD

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Product Development Transition To Lean (PDTTL) Roadmap Release Beta

Prepared by:

Dr. Hugh L. McManus
Metis Design
222 Third St., Cambridge MA 02142
hmcmanus@alum.mit.edu

for the Lean Aerospace Initiative
Center for Technology, Policy, and Industrial Development
Massachusetts Institute of Technology
77 Massachusetts Avenue • Room 41-205
Cambridge, MA 02139

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This document is formatted for double-sided printing and edge binding. Blank pages are inserted for this purpose. Color printing is preferred, but black-and-white printing should still result in a usable document.

ACKNOWLEDGEMENTS

This manual is dedicated to the memory of Joyce Warmkessel, a colleague, mentor, and friend to many in the LAI Product Development and Testing and Space Operations communities. The intellectual foundation of this work was laid by Joyce in both her work at LAI and in her experience in aerospace product development and program management.

The ideas in this work were further developed by the LAI product development community. Major contributors included LAI students Lt. Rich Millard,[1] Tyson Browning,[2] Jim Chase,[3] Robert Slack,[4] Joshua Bernstein,[5] and Brian Ippolito[6] and their advisors and committees. Many other LAI students and staff also contributed as well. LAI product development research work has been based on, and grounded by, the activities of a very active group of industry practitioners, too numerous to name, who have selflessly shared their hard-won practical knowledge.

The text of this manual is built on LAI research and member documents. Some of its contents are excerpts, modifications, or paraphrases of existing work. Every effort has been made to correctly attribute all contributions. Word-for-word excerpts are identified with quotes or indented, with citations. Some other excerpts have been edited to varying degrees and are integrated into the text for clarity. Their sources are cited in the text or in endnotes. Any omissions or errors of attribution should be brought to the author's immediate attention for correction.

Table of Contents

Introduction to PD TTL

Overview

The Lean Aerospace Initiative (LAI) Product Development (PD) Transition To Lean Module (TTL) is a tool for the transformation of PD efforts to a lean state. It has a parallel structure to, and is intended to by synergistic with, the existing LAI Enterprise TTL and Production Operations TTL. It is, essentially, a list of things to think about and do that are specific to the PD problem. It does not endeavor to teach basic lean principles, and it is not an exhaustive tool for the implementation of lean in PD.

The bases of the tool are the basic ideas of Lean (e.g. from basic references such as *The Machine that Changed the World*[7] and *Lean Thinking*[8]), the advanced lean concepts expressed by LAI in the book *Lean Enterprise Value*,[9] (*LEV*) and many years of research and observation of industry best practice from the LAI PD research group. The structure of the PD TTL is heavily influenced by the ideas in *Lean Enterprise Value*. Review of this book, in particular Chapters 7 and 8, is recommended but not required for the understanding of this work.

The PD TTL is aimed, in particular, at two sorts of PD improvement campaigns: improvements of the PD silo organization, and/or improvements of the PD process in the context of a specific program. In the former case, we will refer to the Parent Enterprise, meaning the company or organization for which the PD work is done. In the latter case, we will refer to the Program Enterprise—the set of stakeholders, from customer, through contractors, to subcontractors, engineers, and support personnel, who are involved in the development of, and ultimately production of, a product.

Applying lean to product development has three goals, representing three very different areas of process improvement.[10] They are:

- ***Creating the right products…***Creating product architectures, families, and designs that increase value for all enterprise stakeholders.
- ***With effective lifecycle and enterprise integration…***Using lean engineering to create value throughout the product lifecycle and the enterprise.
- ***Using efficient engineering processes…***Applying lean thinking to eliminate wastes and improve cycle time and quality in engineering

Figure 1 shows a conceptual view of the entire product development process, adapted from Ulrich and Eppinger.[11] The effort in creating the right products is concentrated in the early phases of development, but has a continuing presence. The need for efficient engineering processes is strongest in the "heavy lifting" stages of detailed design and testing. The lifecycle and enterprise integration issues span the entire process, but are most critical as the product transitions to production and is continuously supported throughout its lifetime.

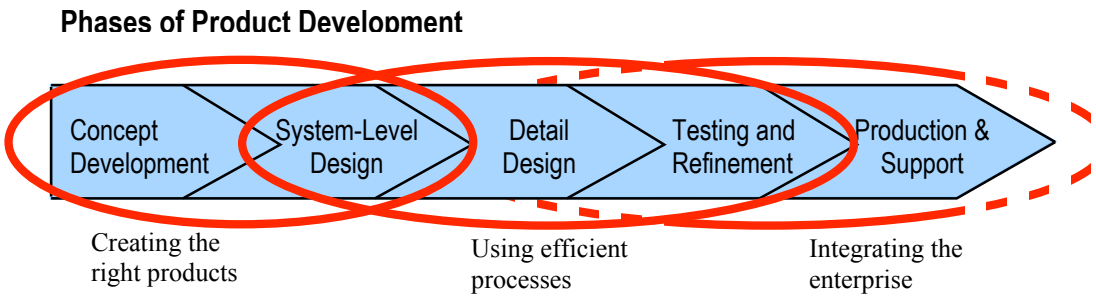

Figure 1. Lean applied to the product development process

In the terms used in *LEV*, "doing the job right" involves minimizing waste, maximizing the efficiency of the process, and assuring quality of both the process and the resulting product. These are the "traditional" jobs of lean process improvement—but they have a unique flavor when applied to PD. "Doing the right job" is, given the enormous leverage that product development has on the lifecycle value of a program, an even more important task. The right product must be created to serve the external customers. The product development must also satisfy the needs of the downstream parts of the enterprise, sometimes referred to as the internal customers. They rely on product development for designs that can maximize lifecycle value through lean production and support, and flexibility and robustness in the use environment.

The PD TTL is built around the PD TTL Roadmap, included at the end of the document. This document starts with definitions of key terms and the relations of the PD TTL to other TTL tools. Then, each element of the Roadmap is explored in some detail. The tone of this exploration will be brief and prescriptive—it will take a "what to do" approach. Related literature, research, resources, and tools are included as references.

Who is the PD TTL for?

The PD TTL is intended for leaders in industry and government who wish to bring lean techniques to bear on product development problems. Program management and program-resident as well as enterprise-wide lean champions should be able to use this tool directly. It should also be useful for lean leaders at the "front lines" of change. This class of change agent has no fixed title—in some firms they are "black belts," in others "lean facilitators," in others they labor without official designation. You know who you are—and this work is for you. Enterprise leadership can use this document to understand the possibilities of lean PD, and participants in lean PD transformations should review it to get a taste of the "big picture" while working their specific problem.

How to use the PD TTL

In- depth study

Tool

The PD TTL presents a framework for lean PD efforts. Although it is not a complete "cookbook" for lean PD from start to finish, it does identify the important high-level steps needed for successful application of lean techniques to PD problems. Where appropriate, it includes pointers to more detailed material. It should be used, first, as a guide to understand the challenges and opportunities of leaning PD. The material on identifying value and constructing value propositions, in particular, will be unfamiliar to most readers, and of particular importance for lasting success and impact in lean PD. Next, it should be used as a guide for planning lean initiatives in PD. The exercise of understanding value and value propositions will point improvement efforts towards the highest-value targets, which may not be obvious at the outset. The PD-specific techniques referenced in the Create Value material will help apply more traditional lean techniques to PD problems. Finally, it should be used as a template, and possibly as a visual control system, for executing lean PD initiatives. Following the steps in the PD TTL, and in particular the feedback loops, should keep a continuing effort on track for maximum impact.

Warning or opportunity

After some introductory material, establishing some definitions, and explaining the basic framework, the elements of the TTL will be explored in detail. The style will be brief and prescriptive—what to do, and how. References will be provided for in-depth exploration. A magnifying glass symbol in the margins will indicate additional reading for depth of understanding. A hammer will identify references to tools. A yellow triangular warning sign will highlight cautionary statements and pitfalls, and also point out where attention may yield exceptional opportunities.

Definition of lean PD

First, we clarify the definitions of Product Development, Lean Product Development Processes, and Lean Product Development Outcomes. All of these phrases are used in various ways in various contexts. The definitions presented here are products of the LAI PD working group, and are intended for use in this document, not as universal definitions.

Product Development: The set of tasks from concept definition to validated product definition

We present this definition to define the scope and applicability of the PD TTL. Concept definition, preliminary and detailed design, and validation and verification are explicitly included; under some circumstances this may also involve low rate initial production. Transition to full rate production is not explicitly considered, although the Lean Product Definition defined below should substantially enable it.

Lean Product Development Processes: Doing Product Development in a way that creates value while eliminating waste

Leaning the PD process can be defined as doing the same tasks (and/or achieving the same outcomes) with a better process. The focus is that of traditional lean: the elimination of waste and improvement of process efficiency. We must also consider, however, processes that enable better outcomes, as defined below.

Lean Product Development Outcomes: a product definition that enables the creation of the product that provides desired value to the stakeholders

This definition encompasses two major features. First, the product defined should be a product that will provide best lifecycle value to the purchasers and ultimate users of the product (often referred to as the external customers) and other stakeholders. Second, the definition of that product should enable lean in processes downstream from product development—the internal customers. This enabling takes two major forms: consideration and design for the major "ilities" (manufacturability, maintainability, operability, etc.) and the provision of the product definition in a form that enables seamless communication with downstream processes.

Relation to Enterprise TTL

In this section, we establish the relationship between the PD TTL and the LAI Enterprise TTL. Here, we refer to the first edition Enterprise TTL Roadmap, published in 2000. Of course, the PD TTL includes PD specific lean concepts from LAI research. Another distinguishing characteristic of the PD TTL is its emphasis on the concepts put forward in the LAI book *Lean Enterprise Value.* The key concepts include a focus on the *Program Enterprise*, the *Value Creation Framework*, and the expansion of lean thinking to involve both *doing the right job* and *doing the job right*. That said, the PD and Enterprise TTL should be used in concert; Enterprise support is critical to any lean effort, and specifically needed for leaning of enterprise-wide processes, including PD processes.

Program enterprise focus

The program is the place where product development takes place. From *LEV*:

> A program delivers a particular product, system, or service within the constraints of a cost and schedule, and itself can be thought of as an enterprise that cuts across many entities, including the prime contractor and its supplier network, partners, and customers (such as the program office if a government program).
>
> A program can also be thought of as a value stream that encompasses the full spectrum of lifecycle processes, from the development of new

> business to requirements definition, design and development, manufacturing and sustainment—with supply chain integration throughout.

Program enterprises are seldom made up of only one organizational entity such as a single company or government organization. Programs are generally constructed from a number of individual (but connected) parts belonging to different parent organizations. We refer to the parent organization(s) as multi-program enterprises to distinguish them from the program enterprise, and because it is unusual for such an entity to be composed of a single program.

Doing the right job as well as doing the job right

The book expands the concept of lean to include not just efficiency of process, but the correctness of product. Figure 2 graphically illustrates the two pillars of the lean program enterprise. Again, from *LEV*:

> The primary challenge in creating program value is to "do the right job" *and* "do the job right." Even a well-structured program will have difficulty generating value from "doing the wrong job"—that is, making the wrong product. And even the best product will fall far short of its potential if its value stream is poorly managed or not well integrated—that is, if the job is not "done right."

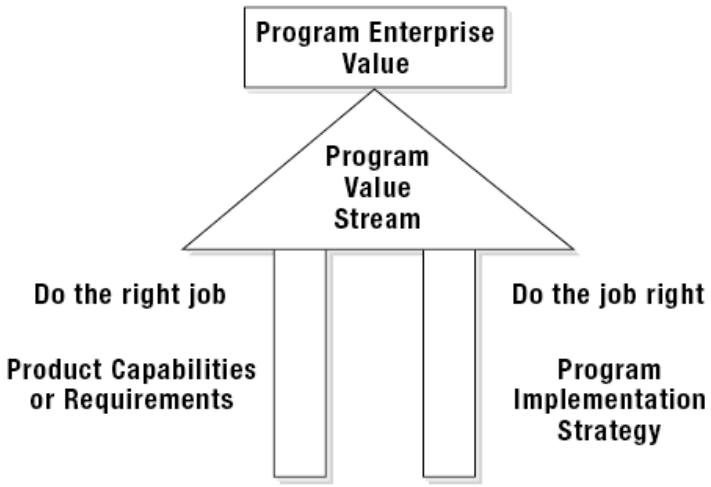

Figure 2. Pillars of Program Value Creation (from *Lean Enterprise Value*)

Value creation framework

The PDTTL has also evolved from that of the Enterprise TTL through the use of the Value Creation Framework. From *LEV*:

> Creating value—with its two elements of doing the right job and doing the job right—is the cornerstone of a successful lean enterprise. But how does the enterprise address these elements? Simply exhorting people to "create value" or "deliver value" is inadequate. It requires systematic processes combined with instinct, leadership, vision, and even a dose of fortunate timing. To help increase the odds of success, we offer the three-phase framework for value creation in Figure 3.
>
> Most lean improvement efforts, such as the use of value stream mapping tools, focus on the last phase of the model: value delivery (doing the job right). Insufficient attention is paid upstream to figuring out the right thing to do in the first place—what we call value identification. Identified value will never be realized until all relevant stakeholders are aligned around one or more value propositions. And the impact of process improvement efforts aimed only at doing the job right will be constrained absent the opportunity to raise the more basic questions about the underlying stakeholder proposition and the initial value identification.

Figure 3. Value Creation Framework (from *Lean Enterprise Value*)

Complementary and synergistic

Both the Enterprise TTL and the PD TTL should be used for leaning product development processes. The Enterprise TTL guides corporate strategy and corporate-wide lean implementation, and should be used in particular when leaning corporate-wide product development processes. It does not, however, support product development lean in particular, and it does not include the "do the right job" pillar so vital to successful product development. The PD TLL can be applied to corporate-wide product development processes, and it does include an explicit tie to the parent enterprise and its lean strategy.

Resources for getting started

The basic concepts of lean are covered in J.P. Womack, D.T. Jones, and D. Roos, *The Machine That Changed The World: The Story of Lean Production*,[7] and J.P. Womack and D.T. Jones, *Lean Thinking*.[8] The LAI book, E. Murman *et al.*, *Lean Enterprise Value*[9] expands these ideas to encompass value creation across the complex enterprises characteristic of the aerospace industry. A high-level guide to transitioning enterprises to lean is covered in the series of manuals available from LAI, "Transitioning To a Lean Enterprise: A Guide for Leaders," usually referred to as the Enterprise TTL.[12]

At a more tactical level, LAI's Product Development Value Stream Mapping (PDVSM) Manual[13] explains the use of value stream mapping methods for off-the-factory-floor processes. The value stream mapping and improvement method was widely popularized by Rother and Shook in their *Learning to See*,[14] which is a prerequisite for understanding PDVSM. The PDVSM manual includes discussion of value in the product development context, assembling teams of stakeholders, mapping current and future states, and various techniques for lean improvement in the PD context. In the context of the PDTTL, it can be used as both a method for understanding value streams, and a guide for assembling teams to do local *kaizen*-type improvements.

A word of caution

The following PD TTL can be used as a standalone document, but obeying it as a cookbook without understanding both the essential ideas of lean and some of the advanced concepts necessary to apply lean to complex enterprises and off-factory floor processes is dangerous. Lean is never a cookbook process; in the words of Hajime Ohba, general manager of the Toyota Supplier Support Center, "Lean is a way of thinking, not a list of things to do." The application of lean is *always* dependent on the particular circumstances of the application; and this is all the more true for the cutting edge challenge of applying lean to product development processes. So, if you must have a list of things to do, start by educating yourself in lean!

Product Development Transition to Lean Roadmap

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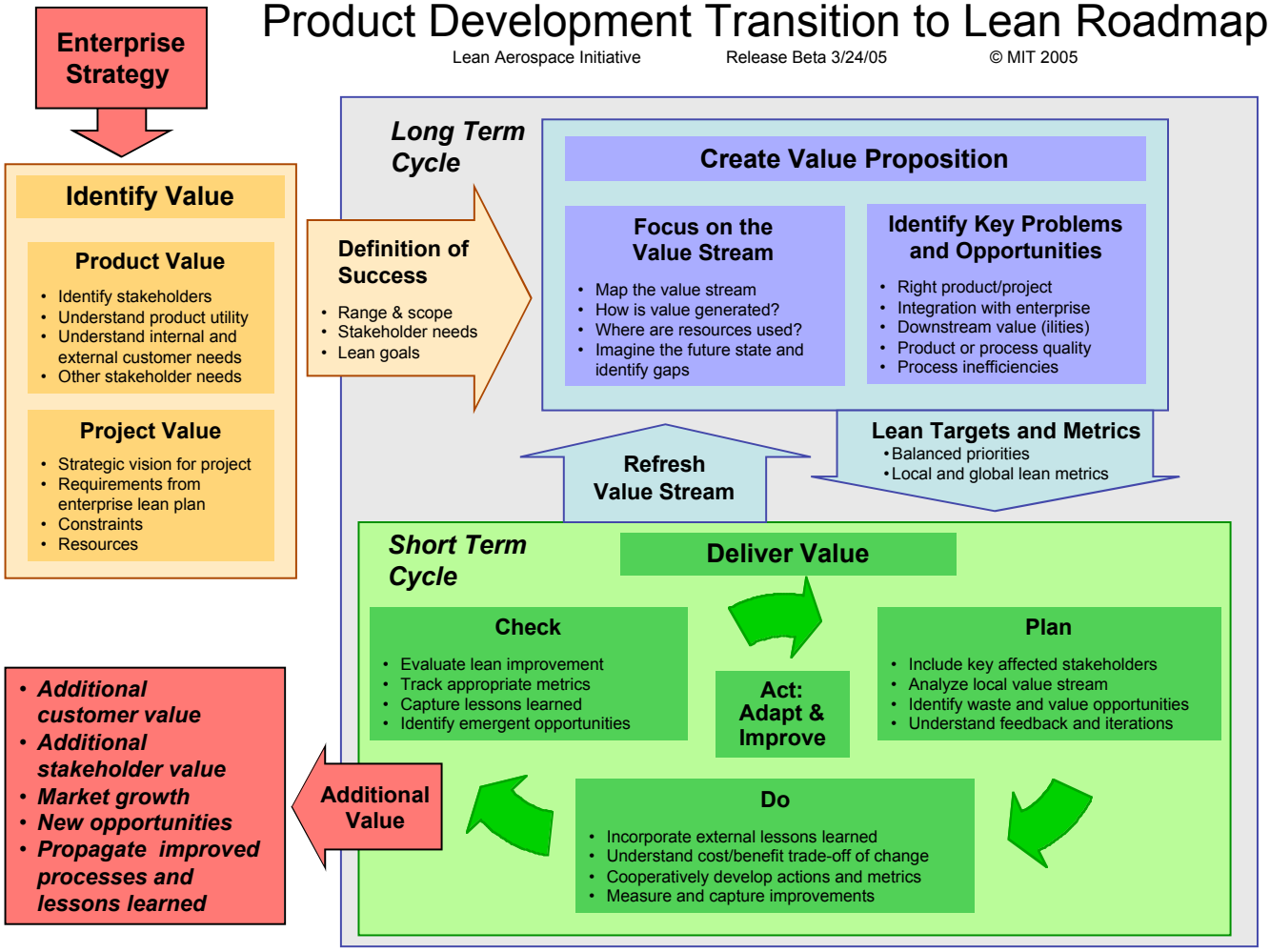

Basic Framework

The PD TTL Roadmap shown above provides the basic framework for the PD TTL. Four major blocks, distinguished by color, are evident. The parent enterprise (red) provides the overall strategy, and expects a set of benefits that will result from the successful implementation of lean in product development. The effort begins with the identification of value (yellow/orange) where the product(s), the expectations of their stakeholders, and the goals of the lean improvement project are considered in order to define explicit success criteria. The value proposition (blue) is driven by an understanding of the current state, the desired future state, and the gaps between them. The periodic reconsideration of this value proposition drives the long-term improvement cycle. Finally, the short term improvement cycle (green) is focused on the delivery of value through systematic planned improvements.

Enterprise Strategy and Benefits

The parent enterprise is the company, program or government organization in which the PD function resides. It is the probable initiator of the lean improvement. It also, by resources provided, lean strategy passed down, and constraints imposed, provides the context in which the lean improvement takes place. It is also a key stakeholder in the improvement, and it is one of the ultimate benefactors of the additional value created.

Identify Value

This, under most circumstances, should be the starting point of a PD lean journey. The value of the product(s) delivered to and used by external customers must be thoroughly understood if it is to be increased. The value that the enterprise expects to gain from lean PD improvements must also be understood. The output of this understanding is an explicit definition of success for lean PD. As external factors such as enterprise strategy and stakeholder needs shift, these definitions will as well, making them both a starting point for, and a continuing input to, the Long Term Cycle.

Create Value Proposition

The long term cycle starts with the creation of a value proposition. The goal here is to understand how lean PD can be a win-win-win proposition for all of the stakeholders. This understanding is gained by considering the high-level value stream of the PD process and the context it is embedded in. The difference between the current state value stream map and the desired future state can be used to identify

problems and opportunities of various types. The output of this step is a set of targets and metrics for detailed improvements.

Create Value Proposition will be revisited periodically, as changing circumstances, advancing knowledge, or limits on short-term improvement force a reexamination of the value stream. This reexamination, along with any necessary re-coordination with shifting enterprise and stakeholder needs, drives the Long Term Cycle.

Deliver Value

This cycle is roughly equivalent in structure to the Short Term Cycle of the Enterprise TTL. It is distinguished in purpose by the emphasis on finding value *enhancing* opportunities in process and product as well as eliminating waste. It starts with targeting opportunities based on the understanding of the value proposition and value stream gained in the Identify Value and Create Value Proposition actions. Implementing the change is covered with emphasis on the particular difficulties of change in PD processes and cultures. Finally, follow-up, an often-neglected aspect of lean change, is covered. Follow-up is necessary to capture and institutionalize the changes for the parent enterprise, to allow the knowledge gained to be used in future programs, and to assure that the learning that takes place during the leaning process itself is captured. This process has no explicit output; its result is change in PD processes and product value. These changes necessitate the periodic refreshing of the value stream, and provide a set of benefits to the larger enterprise.

Identify Value

There are two main components of identified value. The first is the value of the product being designed and produced to the stakeholders who are the ultimate purchasers and users of the product. The second is the value that lean improvement, referred to herein as the "project," provides back to the parent enterprise.

Execution of this phase will typically be done by a working group of lean experts and leaders, with the necessary support of management. However, this group should be certain that input is obtained from all of the key stakeholders, once they are identified below, to assure correct focus and a realistic definition of success.

Product Value

There are three actions in identifying product value. The first is to identify all the stakeholders relevant to this product, and the program that produces it; the second is to identify the product utility; and the third is to make explicit the value that is desired by the key stakeholders. The values are broken down by those delivered to customers, both external (customers of the product) and internal (customers of the PD process outputs, typically downstream functions such as manufacturing and support), and those delivered to other stakeholders.

Identify stakeholders

In any program there are groups that are not the final users of the product that nevertheless have impacts on the program or are impacted by it. The parent multi-program enterprise is an obvious group. The shareholders and employees of the parent enterprise are also stakeholders. In most programs there are other multi-program enterprises (e.g. key suppliers and partners) that are critical to the success of the program. The procuring agency or purchasing organization is an important stakeholder as are the sources of financing and/or purchasing authority. In some programs the public have important stakes in the way the product is designed and manufactured. For example the public are not actual users of a weapon system developed by the US government, but benefit from its existence.

It is critical when identifying stakeholders to think broadly about classes of stakeholders to be sure not to miss an important set. It is equally important to identify major subgroups within classes. For a major PD transformation, stakeholder classes might include customers, suppliers, management, and technical personnel. Customers might include both users and program officers or purchasers; several key suppliers must typically be considered; both program and strategic management should be represented; and several functions from within the parent enterprise will probably needed, including support functions such as IT, finance, etc., as well as the relevant product development disciplines.

Identify product utility

Product utility is the definition of the three important aspects of any product: its performance, how much the user is willing to spend to get the performance and when the product must be operational. This is the familiar performance-cost-schedule triad; all must be considered and weighted.

The first step in defining the utility is to identify explicitly the ultimate user(s) of the product. The user may or may not be the one who directly pays for the product. In this action of identifying the product utility it is the utility of the ultimate user that is sought. The second step is to clearly define what user needs can be satisfied through use of the product. From this an initial set of parameters can be developed to be used as the basis for solution tradeoffs.

One approach is to develop a set of utility relationships. Utility relationships are not identical to the product requirements. Utility relationships seek to identify the attributes of the product's architecture that are key in providing the desired product capability. These attributes are not single values, but rather relationships that can be modeled and enumerated for different combinations of product features or architectures. These utilities do not include cost functions.

Cost is however an important parameter of the product's value. It can be expressed as a fixed budget, or (better) be expressed as a preference than can be traded against different levels of performance. Also the cost level can levy additional requirements on the way the project is conducted. For example, past a certain level of dollars, the government requires additional approvals.

When the product is required to be operational is the final important aspect of utility. It may be that an early introduction with less than full capability provides more benefit than a later introduction with full capability.

While it is always the goal to define a utility that meets all aspects of performance, cost and schedule, unforeseen difficulties often arise in the execution of the program. To aid in developing a robust value proposition, at this stage it is important to ascertain the relative importance of these three.

It may be appropriate to use formal tools to define these utilities. Extensive work at the joint MIT/CalTech/Stanford Space Systems, Policy, and Architecture Research Consortium (SSPARC) in the use of Multi-Attribute Utility to guide in architecture selection for advanced space systems is an example of the use of utility tools for complex problems. SSPARC has produced a collection of academic papers[15] and a final report.[16] The final report is available at the SSPARC and LAI websites. Simpler methods such as the use of Quality Function Deployment[17] or interview or survey approaches[18] can also be used. The key, regardless of technique, is to express the desired product utilities concisely in terms of a number of technical parameters, cost, and schedule that can be weighed and traded against each other and the needs of other stakeholders.

Understand internal and external customer needs

Once the key stakeholders for the program have been determined it is necessary to ascertain the "value" they want from the program. The most direct of these are the needs of the external customers. They include the product utility discussed above, but should not be assumed to be limited to product utility. As an example, external customers often operate under constraints (e.g. budget instability) not formally included in the product requirements. The internal customers are the downstream processes between product development and the delivery of the product to the customer: they may include manufacturing, support, marketing, etc. Their needs may involve product attributes (e.g. producability and maintainability), or they may involve the flow or quality of information about the product (e.g. manufacturing needs accurate specifications, marketing accurate product performance data and availability dates). These are enterprise integration issues, discussed in theory in *LEV*, and in more detail by Haggerty *et al.* in several presentations and papers.[19]

Other stakeholder needs

This is a catchall for the needs of other stakeholders in the PD processes. These may include suppliers (who may place a very strong value on early understanding of their roles in, and potential income from, a new product); technical groups within the parent enterprise (that may see growth opportunities from certain projects): and the engineers themselves (who may place value on working on interesting products, and/or improving the percentage of their time spent doing creative work). These values must be understood to complete the value proposition. They may also be the basis for achieving buy-in and obtaining resources from these stakeholders, both of which will probably be necessary for the lean transformation to be successful.

The best and most straightforward way to gain knowledge of stakeholders' value is to ask. This sounds simple, but it is often a major cultural leap to openly and honestly communicate what a group wants and is willing to give. Trust, preferably at a personal level, is key. Often, if this step can be taken, many benefits can flow directly from simply identifying and communicating stakeholder values (see for example the C-17 story from Chapter 5 of *Lean Enterprise Value*). Issues of establishing these sorts of relationships with supplier networks are covered in the LAI Supplier Networks Transformation Toolset.[20]

Project Value

Here, we define the lean transformation as the “Project.” This word is deliberately vague, as the project may encompass anything from the leaning of the engineering support of a single ongoing program, to the transformation of the product development function of a multi-program enterprise (such as a company), to the ground-up lean design of a new product development program. The PDTTL should be adaptable to all of these circumstances; it is up to the reader to take the words that follow in the proper context.

The project will take place in the context of some larger enterprise's lean transformation, and the expectations of that enterprise must be considered. In this section, we will explicitly identify several elements of value that are almost always present when defining the value proposition for a lean project. This list is *not* intended to be complete; make sure to examine the context of the project carefully for other important values that are specific to your situation.

Strategic vision for project

The parent enterprise should have a lean vision, as outlined in the Enterprise TTL. It is important that the lean efforts to be undertaken within a particular project be done with a conscious relation to the parent enterprise lean efforts. This often means that they directly align with and contribute to enterprise strategy. On the other hand, if product development's lean needs are unique, it may be necessary to act independent of, or be a pathfinder for, the parent enterprise's lean effort. This is not necessarily a bad thing, but it must be done consciously.

The specific question to answer here is, in the context of the parent enterprise's lean strategy, what is the strategic purpose of the PD lean improvement? Is it defensive, to correct quality and costs issues, progressive, to get the PD organization up to recognized level of lean capability, or break-out, to achieve competitive advantage though slashed cycle times and costs and dramatic increases in product utility?

Requirements from enterprise lean plan

In addition to the strategic considerations covered above, the parent enterprise may impose a number of expectations based on the details of the enterprise's lean plan. These expectations could take many forms, and may have wide-ranging impacts on how the lean PD project will be carried out. They may affect tactics more than strategy; for example, the enterprise lean plan may call for certain types of training which will be both a resource and a constraint on for the lean PD effort.

Identify and understand constraints

Because projects are almost always embedded in a parent enterprise, it is important to identify and understand the constraints put on the project. For example the parent enterprise may be required to perform at a set level of process maturity to be able to compete for some business. Hence the project must understand the extent that it must participate in data collection, audits and reviews.

Some of the other areas that may impose constraints are application of standard design and manufacturing processes, use of common tools, labor agreements, directed partnering, requirements on supply chain management and business processes.

Identify and understand resources

The resources that are needed to implement the program are most often provided by the parent enterprise. It is important to identify specifically what the project will require from the parent organization and/or other stakeholders. Areas to investigate are: required investment, personnel to implement the program, training, design and

manufacturing tools, design and manufacturing physical facilities, and level of support from common resources.

Output of Identify Value: Definition of Success

The output of the value identification actions can be partitioned into three main areas. The first is the range and scope of the expected lean transformation. The second is the top-level definition of the customer needs. The third is the top-level goals that he lean effort must meet to provide value to the parent enterprise and other stakeholders.

Range and scope

The scope of the lean PD project needs to be synthesized from the needs and expectations of the stakeholders, the available resources, and constraints such as the higher-level organization of the parent enterprise and the programs within it. Although clearly the effects of lean transformation will spill beyond the boundaries of the PD organization, and transformations will be needed in other organizations to make PD lean fully effective, the scope of *this* improvement effort must be well defined.

Stakeholder needs

These are primarily the needs of the external and internal customers, discussed in the previous sub-section, that should provide the "pull" for lean improvement—the goal is ultimately to provide more value to the customer. Ideally, the needs would be understood in a broad way (not just in terms of technical requirements) and include many customers/stakeholders. This output may also include the needs of key suppliers (e.g. for stability in relationships), program management (e.g. incentives), the workforce (e.g. employment stability, professional challenge and advancement), and other identified stakeholders. These expectations should be as explicit and quantitative as possible.

Lean goals

This output refers to the lean goals and their relation to the parent enterprise lean strategy. Basic qualitative goals are laid out. Is the project expected to a lean pathfinder; to conform to parent enterprise lean practices and goals; or merely to catch up to a minimum acceptable level? Quantitative goals for reductions in cost and cycle time, improvements in product utility, or other metrics as appropriate, should be set.

Create Value Proposition

Having defined success for lean transformation, the next step is to define a value proposition that will deliver that success. The value proposition must satisfying all the stakeholders, so that they have "buy in" and will commit the necessary resources to the transformation. It must be based on current reality, driven by a realistic desired future, and pointed towards key issues, both short- and long-term.

The mechanism for the creation of this value proposition is an event or series of events at which the value stream is mapped and analyzed, the future state brainstormed, and key problems and opportunities for improvement identified. The output of this step is a set of improvement targets and metrics which will be the focus of the following short term improvement cycle.

The value proposition will be revisited periodically, as changes in both external factors and internal processes alter the value stream. The evolution of the value proposition drives the long-term improvement cycle.

Focus on the Value Stream

Understanding both the current state value stream and at least some vision of a future state are necessary for a successful transformation. The point here is to get beyond local issues and find the global issues that affect many stakeholders and have a large leverage over resources used and value generated. Failure at this step will result in local optimization based on fixing local complaints, often at the expense of other stakeholders, and possibly resulting in a *decrease* in global efficiency.

Map the value stream

The program value stream is all the actions and interactions that are necessary to develop the lean product definition. A milestone schedule is an important feature, but is not usually sufficient. A clear plan of how information is exchanged and managed is an important part of the definition of the value stream. Identification of who is responsible for providing and receiving information is also part of the value stream. A PD *function* value stream is more challenging to map, as it is necessarily a composite of the value streams of the PD part of many programs. The idea is to capture the common process that most programs use, so that it can be improved.[21]

The key tool for mapping and analyzing PD value streams the LAI PDVSM. Rother and Shook's *Learning to See* is also mandatory reading. At this level, the techniques of Enterprise value stream mapping may also be appropriate; D. Nightingale and A. Stanke of LAI are developing methods for high-level value stream mapping, dubbed *Enterprise Value Stream Mapping and Analysis (EVSMA)*, that are unpublished as of this writing but which should be available soon. A program perspective on value stream mapping can be found in Brian Ippolitto and Earll Murman, "Improving the

Software Upgrade Value Stream."[22] A deeper discussion of the value stream is contained in the "Analyze the local value stream" section below.

The value stream will typically be created as part of a carefully planned event. Available data on current practices (e.g. published procedures, timecard or financial records, program schedules and plans such as Gantt charts) should be collected ahead of time. The event should include representatives for all key stakeholder groups so that the tacit knowledge of what really happens is captured. Training in VS methods should also be included, either ahead of time or as part of the event. One of many training tools available is the LAI Lean Enterprise Value Simulation training.[23] This training includes a PD module that can be customized for PDVSM events. A theoretical template for such events is contained in the PDVSM; practical examples include the recent LAI Global Hawk and Sensor Fused Weapon (SFW) events.[24]

How is value generated?

The value stream must be understood in all of the usual dimensions, i.e. task sequences, information flows, etc. as identified in the PDVSM. Of particular importance to the project value proposition is the question of value generation. The stakeholders, and in particular the customers, must be explicit about this. Is it simply getting the job done on time, so that production can commence? Is risk reduction and quality insurance of particular importance? Is the integration of systems into networks or systems-of-systems a critical issue downstream? The answer to these questions will strongly impact the definition of value-added, and hence the priorities, metrics, and sense of value-added that will be carried forward into the short term cycle. This issue is discussed further in PDVMS, pp 27-34.

Where are resources used?

This is another question of unique importance to ask when analyzing the value stream. Are the resources available to do the tasks? Are the majority of resources focused on the high-value-added tasks, as identified above? Where would improvements have the most impact on resource use? A common mistake is to concentrate efforts on areas with obvious problems, and miss the fact that their solutions will not free up much in the way of resources. Other areas may be using the majority of resources, and should be targeted even if improvements there are less obvious.

Imagine the future state and identify gaps

The theory behind this step is simple enough—agreeing on the characteristics of a future state, and identifying the differences between the current state and this future state vision. The practice is more elusive. Possible approaches include: a future state based on known lean improvement techniques (see *Learning to See*); a future state "backed off" from an imagined, highly aggressive ideal state vision (used in the SFW event); or a future state based directly on the lean goals and customer needs that make up the definition of success above. Experienced facilitation and imagination are very useful here.

This step MUST be done carefully and well, as it will be the single most important factor in prioritizing detailed improvements. Success here will focus attention on the key steps towards the future state; failure will result in uncoordinated local improvements.

Identify Key Problems and Opportunities

This step should flow directly from the gap analysis in the previous step. The gaps between the desired future state and the current state should be translated into problems with the current state, or value-adding opportunities for the future state. These will have some distinct flavors, which need to be made explicit before plans can be drawn up for detailed improvements. The flavors are captured in the definition of lean product development, explored in Figure 1 and its accompanying text: 1) Creating the right products, 2) With effective lifecycle and enterprise integration, 3) Using efficient engineering processes.

Right product (or project)

If the wrong product is being created, a major rethink is clearly needed. This may result in drastic action, i.e. exiting the market or scraping the current product and starting over. If this problem is systematic (!) it may reflect the need to drastically revamp the early phases of the product development process. In either case, what is wrong must be understood: What user needs are unmet? Is the product too expensive? Are other stakeholders hopelessly unsatisfied (no profit, severe environmental or employee health issues, etc.)? It is also valid to ask, at this stage, if the lean improvement effort (the project) is fatally flawed—for example, a bad product will not be helped by process kaizens. Conversely, a successful product may present opportunities that need to be exploited in a timely manner with minimal extra of resources, stressing the PD function but potential providing a great deal of value to the parent enterprise.

Integration with enterprise

Many problems can be traced to bad communication between functional organizations. If communication between the PD organization and upstream (user/customer) or downstream (internal customer) communities is poor, both bad design and inefficient processes are all but guaranteed. A lesser issue of this sort is the *efficiency* of this communication—if communication with manufacturing is excellent but consists of masses of drawings, when 3-D solid models which both functional organizations use could be transferred, there are major opportunities for improvement.

Downstream value (ilities)

This is a special case of the above, but is so common as to deserve its own category. Designs that satisfy user needs for performance, but which are not manufacturable, maintainable, updateable, or capable of evolution as user needs shift will provide poor lifecycle value. This is something of a truism; however, the forging of a value

proposition is a particularly good time to identify which of the long list of ilities will generate the most value for the customers and other stakeholders, and prioritize improvement in this area accordingly.

Product or process quality

This class of problems has several varieties, which are likely to be discovered via different routes, but which have similar features and potential solutions. Poor end product quality is usually noted by the customer, and can often be fixed by improved product development processes (e.g. design for reliability, mistake-proofing, etc.). Poor quality of PD process outputs (e.g. drawing mistakes, design failures corrected in test and verification) can be identified on the value stream when considering enterprise integration issues, but the fix is inside the PD process, not at the interface. Poor PD process reliability is often a root cause of problems discovered on the PD value stream, such as excessive iterations and rework. It needs to be tackled in much the same way as manufacturing quality problems.[25]

Process inefficiencies

This is the easiest of the problems to understand intuitively. It is often the hardest to fix. It is often a source of misunderstanding and cultural resistance, as PD personnel do not enjoy being described as inefficient, or managed for efficiency. This should not be the case. The PDVSM has a section devoted to the observed inefficiencies in PD processes. Most of them have to do with waiting, queues, poorly arranged tasks, and poorly thought out or obsolete task descriptions, not the work of the engineers on the tasks themselves. Once this is understood, achieving the necessary acceptance is much easier. The PD version of the LEV simulation training is specifically aimed at this issue.

Lean Targets and Metrics

The output of the value proposition is a set of targets for specific improvements, and metrics to guide them. This usually takes the form of a prioritized list of lean improvement initiatives, to be carried out in the short term cycle. These are often captured on an "N-block" chart (see Figure 4), describing the project, its goals and schedule, responsible personnel, metrics and success criteria, etc.

Balanced priorities

In both the selection of the target projects, and their prioritization for resources and schedule, balance must be maintained. A useful tool is the PICK chart, which can be used at the end of the Value Proposition event to prioritize projects with input from all of the stakeholders. A PICK chart is a simple chart, on which the proposed improvement projects are placed. The proposals are rated by the stakeholder group as a whole on two axes—impact of improvement, and difficulty. High-impact, low difficulty projects are no-brainers; the real work is in selection of high-high (and, much less importantly, low-low) projects so that all stakeholders see beneficial impact and the cost and resource burdens are distributed in an acceptable way.

Note that impact should be assessed against the *lean success criteria* developed earlier. There may be some tactical considerations. For example, early in a lean implementation it may be important to have some "quick wins," making assured success more important than impact per dollar.

There is no substitute here for a well-understood value proposition, and a good relationship among the stakeholders. Many changes should be able to be evaluated by comparing options against the value proposition. Those that cannot, perhaps because they are radical or "outside the box" should be evaluated by the stakeholders themselves. If a robust value proposition has been constructed, and continuous, open, honest communications are maintained, this evaluation should not be a major barrier. If they are not, no tools are likely to help. Care should be taken to take into account the value propositions of all stakeholders and not just those that are most impacted by a potential change.

Local and global lean metrics

Each targeted improvement should have explicit metrics to drive it; the overall improvement also needs a set of carefully selected metrics. These are often cost savings targets, but could (and perhaps should) focus more on process performance metrics such as cycle time, lack of errors and rework, or measures of customer satisfaction. The key element here is an explicit understanding of what each stakeholder wants, and what they will contribute, with goals, metrics and incentives all aligned. The stakeholders should be, ideally, incentivized to contribute what they agreed to in order to maximize gaining what they want. The plan should be robust to misfortunes and changes in external environments—incentives must be maintained in the right direction even if circumstances change. Cooperative team behavior needs to be rewarded over individual "gaming" of the system.

Typically, 85% of life-cycle cost is locked in by the end of the product development process, while typically only 15-20% of costs have been incurred. In PD, especially early in PD, cost savings will be smaller than the opportunities for decreasing costs or increasing value downstream. The major savings to be found from eliminating wastes in PD processes are likely to be in *cycle time*. Decreased cycle time has many value-enhancing effects, from quicker time to market to greater requirements stability.[26] Downstream cost savings is also a major opportunity. For example, one can enhance program value by better design for manufacturing or support, or by improved customer satisfaction through a product more aligned with the customer's needs.

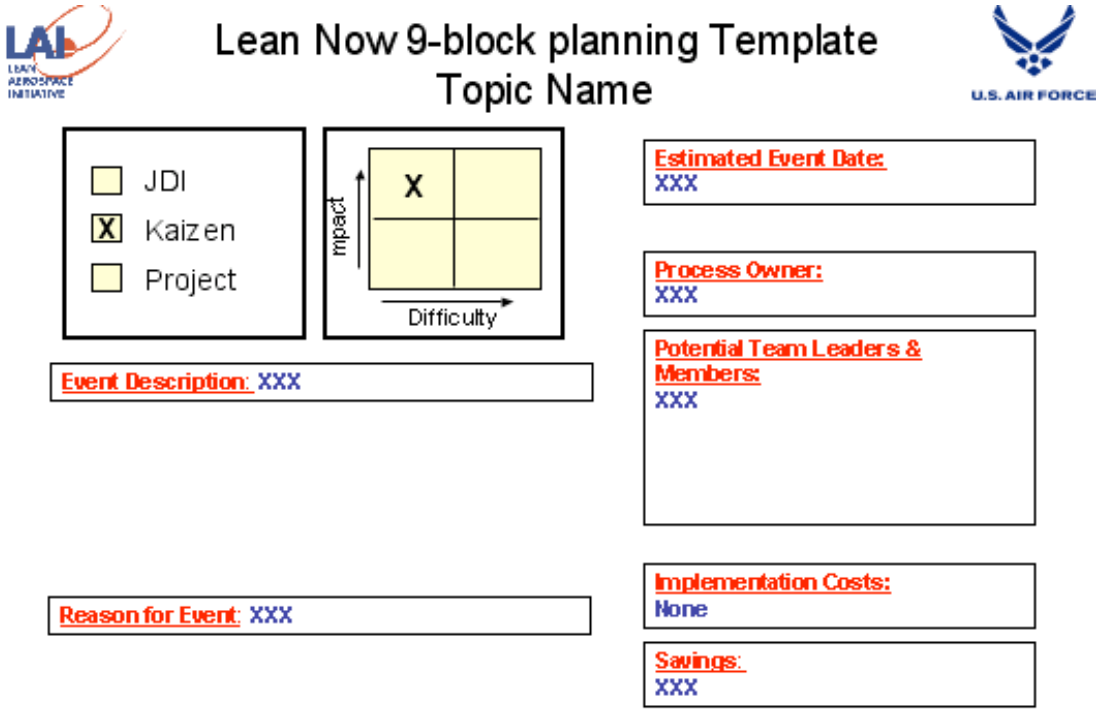

Figure 4. Typical "N-block" form for capturing targeted event

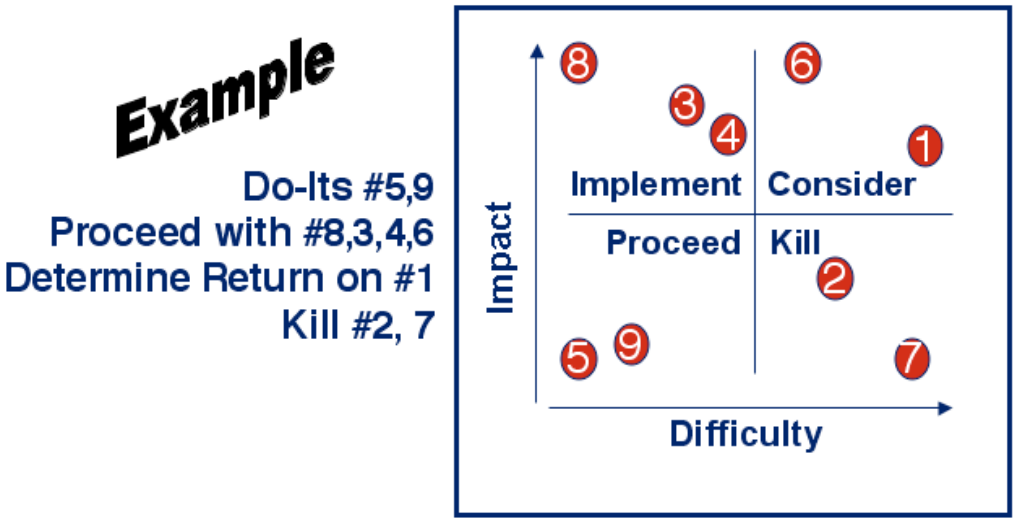

Figure 5. PICK chart for visually sorting and trading improvement targets[27]

Deliver Value

This action, shown in green on the roadmap, corresponds roughly to the Short Term Cycle of the Enterprise TTL. Readers familiar with the Enterprise TTL will find much that is familiar. Those unfamiliar with the Enterprise TTL can find the description of the Short Term Cycle contained in pages 41-63 of Volume II: The Transition -To-Lean Roadmap applies directly. It is written generically; here we will endeavor to adapt and add to the Enterprise TTL to cover both the special needs of PD, and to capture the new insights gained from the value creation framework.

Plan

This activity should begin with the global value stream in hand. The problem here is to understand the local value stream in more detail, which is needed for lean improvements. The basic method is captured in the LAI PDVSM; a quick summary and some extra suggestions are included here.

Include key affected stakeholders

The right change team is key. Ideally, the change team would include the key stakeholders. If that is not practical then some mechanism must exist to represent the interests of key stakeholders. In product development, there is a major cultural resistance to lean improvements growing out of the professionalism and creative energy of the engineers and designers that make up a typical PD team. Failure to achieve buy-in from the "doers" in a process to be improved will result in failure of the improvement effort almost every time. On the other hand, a team with an excessively local viewpoint may not be able to "think out of the box." Millard suggests a team makeup described below.

Analyze local value stream

The basics of value stream analysis are covered in Rother and Shook's *Learning to See* from the perspective of a factory analyzed "door-to-door." Some of the ideas of Rother and Shook can be applied directly to PD, but much of the detail will be different. Product development value streams will track the flow of *information*, not physical goods. The paths the information takes will be more complex, and will include complications such as concurrent flows and iterations *even in the ideal state*. Tracking the information will be harder than following physical goods through a factory as well. Much of the processing and movement of information is undocumented, and where formal processes exist they are often not followed.

Improvement Team Preparation (from Millard)

The improvement team should embody a balance of enterprise perspectives, whether they come from multi-skilled people, or multiple people. These perspectives should include:

- Lean Experts: for knowledge and experience in Lean theory, as well as the methods and tools used for the process improvement.
- Process Owners/Users: for knowledge and experience in the process to be improved, as well as the sources for further information about the process.
- System Thinkers: for enterprise consideration and continuity within the remainder of the business system.
- Customer/Supplier: for product value and external input consideration.

The team must have provided for them training on the Lean business philosophy and the methods and tools chosen... Discretion is required, however, in the use of training materials aimed specifically at manufacturing (which most are). Product Development efforts require distinct training material to "translate" Lean concepts for engineering and design activities.

Richard Millard makes the important distinction between value stream *mapping* and *analysis.* The map is just the graphic visualization of the analysis. In the case of PD, graphic visualizations of complex information flows may be difficult, while achieving understanding from a value stream perspective may be relatively easy. Millard suggests the application of a coarse tool such as a Gantt chart or Ward/LEI map to visualize the value stream at a high level, before boring down with a process map or Design Structure Matrix (DSM) tool. Millard gives some suggestions on how to do process mapping to capture key data for analyzing product development processes (see the thesis). DSM's are tools for tracking information flows; there is a tutorial for them on the web site http://web.mit.edu/DSM maintained by MIT Prof. Steve Eppinger's research group. DSM techniques were demonstrated for analyzing product development processes in Tyson Browning's "Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development."

Identify waste and value opportunities

Analyzing PD value streams for waste is an imperfect art, and is likely to remain so for the foreseeable future. That said, experience indicates some places to start looking. Waste in PD is more likely to involve connections than tasks. Few PD tasks are found to be without value, but often information is lost or mis-communicated. This problem is explored in Josh Bernstein's "Multidisciplinary Design Problem Solving on Product Development Teams." If information is not available, tasks may simply wait; an LAI survey found that approximately 60% of PD tasks are typically idle, waiting for information, staffing, or priority access to resources. This "intellectual work-in-progress" is a direct analog to in-process inventories in a factory, and has the same negative effects on cycle time.

Some preliminary tools are available to identify and understand waste in PD. The Aerojet PD Waste Questionnaire,[28] developed under a ManTech Lean Forum project, is a tool for identifying and classifying waste in PD. The "seven info wastes", first developed at a LAI workshop and now found in various forms as part of several LAI member companies' toolkits, are outlined below.

The Seven Info-Wastes

1 Over-production
- Easy and cheaper to over-produce information, but not good
- Creation of unnecessary data and information
- Information over-dissemination
- Pushing, not pulling, data

2 Inventory
- Lack of control
- Too much in information
- Complicated retrieval
- Outdated information, obsolete information

3 Transportation
- Information incompatibility
- Software incompatibility
- Communications failure
- Security issues

4 Unnecessary Movement
- Lack of direct access
- Reformatting

5 Waiting
- Late delivery of information
- Delivery too early (leads to required rework)

6 Defective Products
- Haste
- Lack of reviews, tests, and verifications
- Requirement is for *knowledge* but *data* is delivered

7 Processing
- Unnecessary serial production
- Excessive/custom formatting
- Too many iterations

Identifying increased value opportunities is even harder. Tools such as automated requirement traceability, cost models or to the like that increase the visibility of customer needs down to the lowest levels of engineering decision making, can help. These tools can, for example, allow proposed changes to the product be evaluated quickly in terms of changes in bottom line cost and/or meeting of customer needs and preferences. The SSPARC research mentioned above is also addressing this issue through techniques for continuously tracking customer utility during design. These techniques are, however, not in general practice, and it may be difficult to implement them solely to make this step in lean transformation easier.

Understand feedback and iterations

The issue of feedback and iterations presents a special challenge to planning PD value stream improvements. Iteration is not always a waste in PD processes, and in fact managed iterations may be more desirable than a slower "right the first time" process, especially early in PD. Consideration of this issue is integrated with the analysis of the value stream, but it is called out separately here to emphasize both its importance and its uniqueness to PD.

Do

Here, we do not list the steps necessary to actually carry out the lean improvement, as they are project-specific. Instead, some steps common to most implementation projects are noted. These are often neglected in the excitement of the actual carrying out of the project, but they should not be. They are necessary to avoid waste in carrying out the project, and capturing the value created by it.

Prior to implementing any change other programs should be surveyed to see if they have any actions or experiences that can help make the change more successful. The cost/benefit trade-off of the change should be quantified in some way, for all of the stakeholders—i.e. a value proposition for the change should be understood. Value delivery from the change is maximized by careful planning, monitoring, and knowledge capture. Implementation plans and metrics should accompany any change. In order to obtain more than short-term benefits, the improvements resulting from the change must be captured.

Incorporate external lessons learned

The parent enterprise and the lean PD community (in particular the LAI community) may have critical experience that will inform the improvement effort. Unfortunately, this information is not centralized, and given the dynamic nature of PD lean efforts, up-to-date information will not be for some time. Here, there is no substitute for participation in a learning community. These communities can be local, at the parent enterprise level (a lean council, etc.) or larger scale (e.g. the LAI PD community). The LAI website, mostly through the records of the PD workshops and LAI Plenary and Executive meetings, has a collection of success stories and work-in-progress presentations. From these, a few lessons can be distilled. Note that these are essentially anecdotal lessons; they are not presented as rigorously supported research conclusions.

At a high level, traditional lean process improvements (e.g. as captured by Millard) have been highly successful when applied to repeated, well-defined procedures such as drawing release or the processing of engineering change orders (e.g. the F-16 Build-To Package Center story in *Lean Enterprise Value*). More complex processes, especially those involving specialized knowledge application (e.g. detailed stress analysis) are much less receptive to this approach. These processes may require the use of advanced technical tools (e.g. advanced CAD/CAE tools, manufacturing

simulations, etc.) to achieve major productivity enhancements. These tools are best applied in the context of a rethinking of the process that they are designed to improve. Poorly defined processes (e.g. fuzzy-front-end concept selection) may require the application of entirely new processes (e.g. SSPARC work) before lean concepts are applicable. Processes that are poorly understood due to diffusion of ownership and responsibility can benefit dramatically by the understanding that even a coarse value stream map provides.[22] If the process is entirely *ad hoc* or experience based, it is difficult to identify a process that can be improved, so a first step may be defining one.

At lower levels, some heuristics are available for evaluating possible lean improvements. The Lean Enterprise Model (LEM) available on-line from LAI, is an early set of principles for lean organization that are still useful. Millard, Alexis Stanke,[29] and Robert Wirthlin[30] all present heuristic rules for evaluating processes and/or carrying out lean improvements. The scope of applicability of each of these heuristic sets must be carefully considered, however. None of them pretend to be universal.

Understand cost/benefit trade-off of change

This can mean doing a Return-on-Investment (ROI) analysis of the lean improvement. This can be a barrier, as traditional ROI metrics can overstate the cost, and understate or entirely miss the benefits, of lean improvements. Better is to evaluate and track the change with an agreed-upon set of lean metrics. Cycle time and projected downstream product flexibility improvements might be benefit metrics. Neither of them are easy to understand in terms of ROI. Cost might be easier to track (in terms of engineering hours), but the most important costs might be in terms of disruption of the current routine or the risks inherent in change. The key here is a self-consistent set of definitions that align with the definition for success for lean improvements (defined above) and are consistent with the program value proposition.

Cooperatively develop plans and metrics

The team should develop the improvement plan, the success goals for the particular improvement effort, and the metrics to be tracked to assure the goals are met. We have no one methodology to suggest for putting a lean improvement plan together. A typical process is described by Millard.[1,13] It is particularly applicable to improvements focused on eliminating waste in, and improving the efficiency of, necessary processes. On the other hand, value enhancing plans may involve adoption of new tools, design changes to the product, or altered relations with suppliers and partners—there is no one recipe for this diverse list of possible improvement paths. The important thing is to have a plan, and metrics by which to track its progress.

Measure and capture improvements

The critical part of this step is the capturing of improvements. Implemented initiatives need to be tracked against the lean success metrics established in the value proposition. This tracking needs to begin with the improvement implementation, but

has no credibility if it ends there. Putting "projected" savings on a viewgraph and declaring victory will not do the job. Lean metrics need to be continually tracked.

Ideally, the metrics would become a part of the process itself, so that they are collected as part of the work, and not as extra work that will tend to get dropped. If a repeated process is converted to a continuous flow cell, for example, the sign-in and sign-out times for a work package automatically track the cycle time. Similarly, work done on a common database will have records of data access that can be used to generate cycle time, idle time, handoff, and other metrics. It is a relatively minor tweak to the process to make the calculation and display of these numbers automatic or nearly so. This will insure continuous tracking, to capture progress and arrest regression to the mean—the natural tendency of processes to regress to their old state if untended.

Check

If the improvement is to have impact beyond a single instance of product development in a specific program it is necessary to have a set of follow up actions.

Evaluate lean improvements

Having captured the lean improvements (see above) it is now time to evaluate its impact. The lean improvements can be evaluated against lean goals as a way of rating the success of the initiative. They can also be correlated against improvements in standard business metrics. This step is extremely important in providing justification for lean improvements. As discussed above, traditional business metrics may not capture the direct effect of lean improvements, but should improve as the program becomes less wasteful and more customer responsive due to lean.

Track appropriate metrics

This should be an integral part of the improvement plan. It is emphasized here because of its importance—it is the meaningful feedback that allows long term tracking of lean improvements, and can be reported back to the larger improvement team when it is time to iterate the long term cycle. It also quantifies the added value returned to the enterprise in the step below.

Capture lessons learned

If the evaluation above shows success, the path to that success needs to be captured. We have emphasized that there are many situations and circumstances in PD, and no one method will work for all cases. Lean PD in general is an immature art. These factors make the lessons learned in a successful initiative, in your environment and culture, extremely valuable.

Unfortunately, there is little evidence that generic knowledge management tools are effective for this class of experience-based knowledge. The overhead on any process that requires participants to record their learning after a lean initiative is likely to

discourage participation. As mentioned above, some things can be captured automatically by the process, but the key knowledge is likely to be in peoples' heads. Therefore it is vital that people-centered mechanisms be used. In the "Incorporate external lessons learned" activity above we said there is no substitute for participation in a learning community. It is now time to return knowledge to that community.

Identify emergent opportunities

Finally, learning that takes place both during program execution and lean improvements can lead to the emergence of new opportunities for value creation. When one waste bottleneck is cleared, new ones may become targets. More importantly, as the product and process become better understood, value enhancement opportunities are revealed. These may be minor product or process improvements which feed into the next round of the Adapt and Improve cycle, or they may be major opportunities that enable a positive rethinking of the program value.

Additional Value

The point of the lean improvement is to deliver extra value to the stakeholders. These are the ultimate metrics of success of lean improvements; they should be tracked, and the results fed back into the enterprise strategy.

Additional customer value

The form this will take will depend on the needs of the customer, hopefully considered early in the effort. Lower cost, higher quality, greater quantity for the same cost, faster design cycle time, greater capability to evolve or adapt the product to changing needs, and greater capability to integrate the product into fielded systems of systems are all customer values that have been delivered by lean improvements. You may pick from this list, or add to it.

Additional stakeholder value

This outcome has even more forms than the above. A key stakeholder is of course the parent enterprise, which typically wants greater revenue and profit. These can be provided by cutting costs, either directly (in the PD process) or by enabling savings in downstream processes (lower cost manufacturing and servicing). Suppliers want revenue, stability, and a share of the improvements generated; functional organizations want retained or increased expertise; employees want interesting work and security.

Market growth

Lower costs, faster cycle time, higher quality and higher customer satisfaction can lead to market growth from both existing customers and growth of the customer base.

New opportunities

All of the above considerations may enable a lean PD organization to take advantage of new opportunities. The efficiency of the lean process will also free up the resources necessary to exploit them.

Propagate improved processes and lessons learned

Finally, the experience gained by achieving lean PD can be expanded to other programs, divisions, or organizations at the parent enterprise, to other contractors by the customer, and down the supply chain. This will allow all the other payoffs to be replicated, and (especially for a pilot or exploratory project) may represent the biggest payoff of all.

Notes and References

Note that most LAI products, thesis, reports, and conference proceedings are available on the web at http://web.mit.edu/lean. Access to some documents is restricted to LAI members. Contact the LAI staff for LAI documents not found on the web site.

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[1] Millard, Richard L., "Value Stream Analysis and Mapping for Product Development," Master's thesis in Aeronautics and Astronautics, Massachusetts Institute of Technology, June 2001.

[2] Browning, Tyson R., "Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development," Doctoral thesis in Technology, Management and Policy, Massachusetts Institute of Technology, December 1998.

[3] Chase, James P., "Value Creation in the Product Development Process," Masters thesis in Aeronautics and Astronautics, Massachusetts Institute of Technology, December 2001.

[4] Slack, Robert A., "Application of Lean Principles to the Military Aerospace Product Development Process," Masters thesis in Engineering and Management, Massachusetts Institute of Technology, December 1998.

[5] Bernstein, Joshua I., "Multidisciplinary Design Problem Solving on Product Development Teams," Doctoral thesis in Technology, Management and Policy, Massachusetts Institute of Technology, February 2001.

[6] Ippolito, Brian, "Identifying Lean Practices for Deriving Software Requirements," Masters thesis in Engineering and Management, Massachusetts Institute of Technology, February 2000.

[7] Womack, James P., Jones, Daniel T., and Roos, Daniel, *The Machine that Changed the World: The Story of Lean Production*, HarperCollins, New York, 1990.

[8] Womack, James P and Daniel T. Jones, *Lean Thinking*, Simon & Schuster, New York, NY, 1996.

[9] Murman, E., Allen, T., Bozdogan, K., Cutcher-Gershenfeld, J., McManus, H., Nightingale, E., Rebentisch, E., Shields, T., Stahl, F., Walton, M., Warmkessel, J., Weiss, S., and Widnall, S., *Lean Enterprise Value*, Palgrave, London, 2002.

[10] This discussion adapted from McManus, H. L, Haggarty, A., and Murman, E., "Lean Engineering: Doing the Right Thing Right," accepted for presentation at the 1st International Conference on Innovation and Integration in Aerospace Sciences, 4th – 5th August 2005, Queen's University Belfast, Northern Ireland.

[11] Ulrich, Karl T., and Steven D. Eppinger, *Product Design and Development*, McGraw-Hill, Boston, 1995, pp. 14-18. This book, and the updated 2nd edition, 1999, are excellent introductions to thinking about product development as a process.

[12] *Transitioning to a Lean Enterprise: a Guide for Leaders*, Lean Aerospace Initiative, Massachusetts Institute of Technology, 2000, available on the LAI website http://lean.mit.edu

[13] Hugh McManus, *Product Development Value Stream Mapping, Beta Release*, Lean Aerospace Initiative, MIT, Cambridge MA, March 2004. Available to LAI members at http://lean.mit.edu

[14] Rother, Mike and John Shook, *Learning To See: value stream mapping to add value and eliminate muda*, Lean Enterprise Institute, Brookline, MA, 1999. Available at http://www.lean.org

[15] Twelve papers in the same issue of *AIAA Journal of Spacecraft and Rockets*, starting with Hugh L. McManus, Daniel E. Hastings, and Joyce M. Warmkessel, "New Methods for Rapid Architecture Selection and Conceptual Design," *AIAA JSR,* Vol. 41, No. 1, Jan.-Feb. 2004, pp. 10-19.

[16] Hastings, D. E., and McManus, H. L., "Final Report of SSPARC: the Space Systems, Policy, and Architecture Research Consortium (Thrust I and II)," Massachusetts Institute of Technology, Cambridge, MA, 2004, available at http://web.mit.edu/ssparc under "About SSPARC."

[17] Hauser and D. Clausing, "The House of Quality," *Harvard Business Review* 66:3 (1988), 63-73.

[18] See, for example, A. Griffin and J.R. Hauser, "The Voice of the Customer," *Marketing Science* 12:1 Winter 1993.

[19] See, for example, the paper "Lean Engineering: Doing the Right Thing Right," referenced above.

[20] "Supplier Network Transforation Toolkit, Version 1.0," March 2004, available at http://lean.mit.edu

[21] See for example Secor, D. and Bliss, D., "Transforming the Product Development Function," LAI Plenary Meeting, Dana Point, CA, March 24, 2005.

[22] Ippolitto, B. and Murman, E., "Improving the Software Upgrade Value Stream," LAI Report RP01-01, September 2001, available on the LAI website http://lean.mit.edu

[23] McManus, Hugh L., and Rebentisch, Eric, "Lean Enterprise Value Training Simulation," Lean Aerospace Initiative, Massachusetts Institute of Technology, 2004, or see http://www.metisdesign.com/game_example.htm. Periodically, short courses using the simulation are given; see the LAI website under "Event Calendar."

[24] Bentley, G., and McManus, H., "Textron Sensor Fuzed Weapon VSM Event: Using LAI Tools to Transform a Program Enterprise," planned for presentation at LAI Plenary Conference, March 2005, will appear at http://lean.mit.edu

[25] e.g. by standard work, in-process inspection, mistake-proofing, visual signals, etc. The is some discussion of this in the PDVSM; many more ideas can be surfaced by considering the manufacturing lean literature and applying some imagination as to how the techniques can be applied to PD.

[26] See Ross McNutt, "Reducing DoD Product Development Time: The Role of the Schedule Development Process," Ph.D. Thesis, Massachusetts Institute of Technology, December 1998; the early chapters of the PDVSM also discuss these issues.

[27] Pick chart illustration adapted from Secor and Bliss, above.

[28] *Learning to Develop: A Guide to Understanding and Applying Lean Principles to Product Development*, Aerojet-General Corporation, Sacramento, CA, 2002, http://www.learningtodevelop.com/default.htm

[29] Stanke, A., "A Framework for Achieving Lifecycle Value in Product Development," Master's Thesis, Massachusetts Institute of Technology, June 2001.

[30] Wirthlin, R., "Best Practices In User Needs/Requirements Generation," Master's Thesis, Massachusetts Institute of Technology, February 2000.

