Production Operations Level

Transition-To-Lean Roadmap

Production Operations Transition-To-Lean Team

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Abstract

This paper provides a roadmap for transitioning an existing production operation to one that fully implements a Lean manufacturing philosophy. Integration of engineering, human resources, and business viewpoints are incorporated into the roadmap to provide a systematic implementation process. Specific actions, in order of precedence, are organized into major phases with points of interface defined with other systems that are both internal and external to the business enterprise. Definitions of those terms used on the roadmap, which are unique in describing Lean activities and practices, are also presented in this paper. The roadmap is based upon experience gained to date by members of the Lean Aerospace Initiative in implementing Lean philosophy into production operations at various aerospace facilities and validated by research conducted by this Consortium at the Massachusetts Institute of Technology.

How to use the Production Operations Transition-To-Lean Roadmap

The Production Operations Transition-to-Lean Roadmap (Figure 1) provides a guide for transitioning an existing production operation to one that fully implements a Lean manufacturing philosophy and Lean best practices. The roadmap defines a systematic implementation process, specific actions in order of precedence that are milestones in the journey from mass to Lean production. The model is organized into major phases with points of interface defined with other systems that are both internal to production operations and external to the business enterprise.

The Production Operations Roadmap is not a cookbook of actions that must be strictly followed for every implementation. Rather, every implementation will be unique in that every enterprise has its own culture, and legacy policies and systems that will either support or impede the journey to Lean. The various phases should be regarded as tollgates or checkpoints to ensure that the elements listed in the prior phase are in-place to some degree or are being addressed, prior to proceeding to the next phase.

It is also important to note the iterative, continuous improvement aspect of these Production Operations Transition-to-Lean Roadmap phases. There is no absolute level of Lean, just incremental steps towards “perfection”. Just like in Kaizen activities, the “To-Be” state becomes the “As-Is” state for subsequent Kaizen events, the current state of Lean becomes the baseline for further localized improvement or extension and integration into the enterprise.

Background

Lean is a term that was coined during the International Motor Vehicle Program (IMVP) bench-marking study in the late 1980's at MIT to describe the Toyota Production System [Womack, Jones, and Roos, 1990]. During this study, researchers found that Toyota clearly stood above their competitors around the world with the ability they developed to efficiently design, manufacture, market, and service the automobiles they produced. This ability made a significant contribution to both their company's profitability and growth as consumers found their products to simultaneously exhibit both quality and value. The focus on recognizing and eliminating wasteful actions and utilizing a greater proportion of their company's resources to add value for the ultimate customer was found to be the key of their operating philosophy by the researchers. Lean Production in comparison to Mass Production was shown to require one-half the time to develop new products, one-half the engineering hours to design, one-half the factory hours to produce, and one-half the investment in tools, facilities, and factory space [Monden, 1993; Ohno, 1990; Shingo, 1989].

The United States Air Force, under the leadership of Lt. Gen. Thomas Ferguson, became aware of the IMVP study results and decided to determine if Lean Production systems could be applied to defense system acquisition programs. Specifically, the government wanted to apply Lean principles to reduce the overhead costs of the acquisition and logistics infrastructure, lower the total ownership cost of defense systems, and field high quality defense products quickly and support them responsively. The Lean Aerospace Initiative (LAI) consortium was founded with MIT as the unbiased arbiter to facilitate broad-based changes in acquisition reform. LAI was organized in 1993 with membership from academia, organized labor, government, and industry that are stakeholders in defense systems acquisition [Lean Aerospace Initiative Web Site, http://web.mit.edu/lean/].

The focus during Phase One (Sep. 1993 to Sep. 1996) of the consortium was on detailed benchmarking studies of aerospace companies in all facets of their operations, resulting in numerous reports and theses being published. A Lean Enterprise Model, commonly referred to as the LEM, was developed to be the primary integrative document for all the products of the Consortium. The LEM recognizes the Meta-Principles of Waste Minimization and Responsiveness to Change, which are composed of twelve separate overarching practices, sixty enabling practices, and over 300 supporting practices.

Phase Two (Sep. 1996 to Sep. 1999) of the consortium looked at Lean enterprises from a total system perspective rather than the focus on distinct practices found in Phase One. While the LAI and others have published many descriptions of Lean practices, there is little published on how to transform a large aerospace manufacturing enterprise from a mass production paradigm to a Lean one. This lack of implementation research led to an effort by a group of Consortium members to develop a road map of actions needed to become Lean into an order of precedence with sufficient detail to be of practical value.

Development of the Roadmap

Upon seeing the need and interest by members of the Consortium to understand the transition to the Lean process more fully, a small team was organized by the LEM IPT. The team's objective was to develop an approach and to construct a Transition-to-Lean roadmap for production operations based on existing models and implementation experience received from both industry and academic sources. Members came from the already existing Factory Operations Focus Team and the LEM Implementation Product Team in late 1998 (see the Acknowledgments section of this paper for the membership listing) to pursue this objective.

The approach consisted of the following steps:

1. Develop an understanding of each of the existing transition models shared with the Consortium. - A total of six models were reviewed, four from industry and two from academia.
2. Acknowledge each model's parameters. - Parameters noted included the degree in which the models addressed technical, people, and business concerns, as well as the overall approach of the model. The review concluded that the models approached the process from three different directions i.e., Entry Vision, Top Level Flow, and Detailed Activity Flow.
3. Determine each model's pros and cons based upon what is of real value in the process determined by the body of knowledge gained to date by the Consortium's research and the real world experience of the team members.
4. Define requirements for a common model. Four requirements were defined and are shown below.
5. Integrate requirements and pros of each into a common Transition-to-Lean Roadmap. See the roadmap included in this paper.
6. Review the new roadmap with the Factory Operations Focus Team and LEM Integrated Product Team. - This was completed during meetings held in March, May, and July of 1999.
7. Obtain feedback and incorporate suggestions for improvement to the roadmap.

Requirements for a common Production Operations Transition-to-Lean Roadmap consisted of:

1. Consistent and synergistic with the Enterprise Transition-to-Lean Roadmap being developed by the LEM Implementation Product Team (see figure 2).
2. Show order of precedence and continuous improvement feedback loops.
3. Summarize scope and breadth on one page.
4. Provide common framework for communicating to all organizational levels.

Production Operations Roadmap Explanation

The Production Operations Level Roadmap (see Figure 1) consists of eight phases of implementation overlaying two broad interfaces shown as backdrops. The first backdrop represents the interface of the Production System to the remainder of the business enterprise. Those business systems and processes that will require changes and/or new interfaces to be developed are noted in this area of the Roadmap. The second backdrop represents the overall supply chain to the ultimate customer that lies outside of the immediate business enterprise and the regulatory and legal requirements of the environment in which the business enterprise operates. Each of the eight phases of implementation shows a number of specific actions in a recommended order of precedence. Phase 7 is unique in that the actions shown may take place at any and at numerous times concurrently with Phases 2 through 6. Phase 7 is indicative of the fact that transitioning an organization to Lean is a learning journey. Each organization is unique and a common path for all will not always work. Internal progress review or feedback should be taken often and the path to Lean may need some alteration or enhancement once underway to get the performance results desired.

Supply Chain/External Environment Backdrop

External suppliers are critical contributors to the product value stream. Policies for interacting with suppliers have to balance the differing needs of individual products/programs in order to achieve the optimum overall benefits to the enterprise. Again, such issues should be handled in conjunction with the Lean Focus at the Enterprise Level. Likewise, there are a number of legal and environmental constraints, as well as government regulations and requirements (Material Management Accounting System - MMAS, Earned Value Management System - EVMS, etc.) which are outside of the boundaries of production operations, and therefore, must be dealt with at the enterprise level.

Enterprise/Production System Interface Backdrop

In the course of implementing the actions in the eight phases, barriers will often be encountered because of policies and practices within the enterprise that fall outside of production operations. These issues should be elevated to the Enterprise Level for help in resolution.

Phase 0 - Adopt Lean Paradigm

Introduction - Phase 0 of the Production Operations Roadmap is identical to Phase 1 of the Enterprise Level Roadmap (7). This duplication at the beginning phase was done so as to ensure a common point of integration. This allows the transformation to be viewed in the context of either Production Operations or as part of the total Enterprise Lean transformation. The details of the process steps outlined here should be made more specific to Production Operations if this is where the transformation begins.

Input - Decision to pursue a transformation of the business enterprise.

Process -

0-1. Build Vision - Considerable effort is required to understand the Lean paradigm and then to interpret the underlying principles and practices as they would apply to your company. It will likely be necessary for several senior managers to acquire the in-depth knowledge and insights associated with Lean, and to begin building a shared vision within the company of how it would look and behave if it became Lean. Attending seminars, conferences, workshops and leadership exchanges can be helpful, in addition to appropriate readings.

0-2. Establish Need - Experience has shown that few companies are willing to make the dramatic, pervasive changes required unless they are experiencing a major challenge or even a threat of survival. It is very unfortunate that this seems to be the case, because the transformation could be accommodated with less trauma if attempted when the company is stable and healthy. Nevertheless, it is useful to define a particular forcing function as a stimulus to begin the Lean transformation. This can best be done as an outgrowth of the strategic planning process. Through assessment of alternative approaches, determine that Lean is the best choice to address the major threat and to position the Enterprise for its future competitive environment.

0-3. Foster Lean Learning - Essentially all key leaders need to be brought up to speed on the Lean paradigm. Regular, frequent meetings need to be organized. Outside consultants can be utilized. The Enterprise Leader needs to develop insights into which senior managers may be unable or unwilling to effectively lead this change. This applies not only to managers at all levels, but also to supervisors and shop stewards if the company is unionized. Lean thinking must be learned; mass production thinking must be unlearned. An overall framework must be developed to foster Lean learning. Visits to other organizations which have successfully transitioned to Lean are particularly helpful.

0-4. Make the Commitment - The top manager in the business unit, with the understanding and support of senior managers, is responsible for making the go/no–go decision regarding Lean. If the business unit operates under a broader corporate structure, the next higher level needs to understand and hopefully support this decision. There should be no ambiguity regarding decision authority or resource control relative to the decision to pursue a Lean transformation. There is a compelling argument that conversion to Lean requires a comprehensive approach; i.e., the various Lean principles and practices should not be implemented selectively but as a total "enterprise thought system". The Enterprise Leader and senior managers should recognize that significant resources (particularly the time of the workforce) may be required. Although there may be barriers to implementation external to the organization's ability to control, the commitment made implies a decision to support with resources and attention those items that can be changed and to work with others to reduce those barriers not controlled internally.

0-5. Obtain Senior Management Buy-in - The decision to pursue Lean, once made, must be viewed as non-negotiable and irrevocable. Full buy-in of all senior managers is mandatory. Expectations of each manager must be made clear. They all must realize that the company is embarking on a great voyage, into only partially charted waters. Doubts must be put aside and replaced with creative solutions to the inevitable challenges that will arise. The considerable risks are balanced by the potential of tremendous advancement in competitiveness. Senior managers are the key link between the Enterprise Leadership and the workforce. The success of the Lean transition depends critically upon full buy-in of senior managers. Senior managers who prove to be unable or unwilling to change must be replaced. It is frequently to a company's advantage to aggressively recruit leaders from the outside who have been successful in guiding Lean transformations.

Output - The decision to change the organization's operating philosophy to Lean.

Phase 1 - Prepare

Introduction –The preparation phase is where the strategy is defined and the support structure is put into place for the transformation to Lean. This phase also marks the point on the Roadmap where a production operation focused Lean transformation starts to take a different but complimentary path from a transformation from an entire enterprise focus. During this phase a cross functional group is established and given the authority, responsibility, and accountability for the transformation. Interfaces with other parts of the enterprise and key business systems are recognized and defined. Major issues such as workforce changes and culture attributes are surfaced and addressed. Knowledge of Lean principles and practices begin to be learned by key parts of the organization. Policies and guidelines are set into place as well as the metrics to measure implementation progress.

Input – Leadership commitment to become Lean from the very top level of the organization.

Process -

1-1. Integrate with the Enterprise Level - Transitioning production operations to a Lean operating philosophy cannot be done to its maximum potential without integration with the other business functions. A major shift towards Lean practices implemented in the shop areas alone will directly impact the operations in procurement, materiel management (stockrooms and production control), product definition, facilities, human resources, and financial management. These areas not only need to be aware of what is being done but also must become part of the process so that their internal operations can be modified to facilitate the change. A good way to coordinate and ensure good integration of activities is by setting up an Enterprise Lean Council or Enterprise Lean Integration Team.

1-2. Establish an Operations Lean Implementation Team(s) - A team consisting of at least one senior level leader from each of the principle production operations areas and points of contact from key areas such as: human resources, public relations, procurement, marketing, business management, engineering, information services and program offices. The mandate of this group is to:

A. Develop a high level strategy.
B. Plan for its execution.
C. Provide resources when needed.
D. Identify and break barriers to implementation as they are encountered.
E. Monitor and ensure that overall implementation is not adversely impacting current performance.
F. Frequently report on progress directly to the senior leadership of the organization.
G. Provide training in Lean principles and tools.
H. Facilitate Lean implementation projects.

1-3. Develop Implementation Strategy - Strategically determine where to concentrate your efforts to maximize the total benefit while achieving the overall objectives of the enterprise's long-range strategic plan. The key question here's: "Where should we spend our time?" To answer this you must ask: "Where are the opportunities for improvement?"; "Which improvements would create the most value for our customers?"; "Which improvements can be defended from competition?"; "What can we do that no one else can do?"; and "How can we differentiate ourselves from the competition?" The premise here is that a strategically focused Lean implementation will produce a quicker and a much more lasting benefit to the company *(6).*

1-4. Develop a Plan to Address Workforce Changes - Experience has shown that people more than anything else are what makes an organization either excel or fail in performance. During the course of becoming Lean, people will be transitioning in their work roles. There will be skepticism as to the real motives for this initiative. Layoffs during implementation should be avoided if at all possible. Any foreseen layoffs should take place before the start of implementation. However, it is critical that a clear and fair policy be established at the beginning to address workforce changes during the process of becoming Lean, including changes in job content, transfers/reassignments, and the possibility of reduced staffing levels. Communicating the need to change in order to sustain and grow the business by cutting costs and becoming more responsive to customer needs is often the case and should become part of the message. It also helps to develop trust by having high level leaders make a strong visible commitment by directly participating in the implementation. Any workforce reductions perceived to be connected with Lean could stall implementation.

1-5. Address Site Specific Cultural Issues - Design the Lean implementation program to suit the nature and needs of the organization. Every organization has its own personality and uniqueness. Strictly following another company or division's success story may be your failing. Strive to develop buy-in by the workforce early and maintain the momentum of the value they see in the changes taking place. Teaming is another essential. Employee teams need to be structured so employees are able to contribute ideas and suggestions to the changes being made. They need to take some ownership of the change, view the new process as theirs and feel that they have control of the outcome of the process. To obtain this wide buy-in it is often useful to establish appropriate stakeholder partnerships. Orchestrating some early successes (wins) to demonstrate the benefits helps to build buy-in.

1-6. Train Key People - Training should start with the senior leadership with the objective of obtaining a correct understanding of Lean principles and what their role will be as the organization moves toward becoming leaner. The next training group will include those individuals that will be leading Lean projects. Their training will be much more intense and consist of both theory and hands on application under an experienced teacher and practitioner of Lean practices. The third training group is the balance of the organization, they should receive a short course on Lean philosophy as well as the organization's plan for implementation. A Lean library, resource center, or on-line tool-kit may be established for anyone who would like to learn more.

1-7. Establish Target Objectives (metrics) - A few high-level target objectives that everyone in the organization can both visualize and contribute to attaining needs to be established and communicated. This can take the form of a balanced set of metrics such as product throughput time reduction, total product cost, customer satisfaction scores, and overall product quality are some examples. Often the metrics will drive behavior, therefore, it is important to ensure that the metrics chosen will influence the

Lean behavior planned. It is essential that the metrics chosen are aligned with the enterprise metrics. This is another important linkage with the enterprise efforts. This action can also be enhanced by using a catchy motto such as “222 Aircraft for the Price of 200”, or “Lean Today Here Tomorrow”.

Output - A strategic plan for implementing Lean that addresses:

A. Leadership and organizational support
B. People and organization cultural issues
C. Target objectives and metrics
D. Training

Phase 2 - Define Value

Introduction – At this phase of implementation the focus is placed upon understanding value in the eyes of the customer and those processes most directly related to providing this value. The area of initial implementation may initially be very narrow such as a specific family of parts, sub-assemblies, or a particular manufacturing process. A more ambitious and risky approach for an initial implementation may be for a large or complex assembly or for an entire manufacturing facility or site.

Input - A strategy as defined in Phase 1 that clearly defines where the maximum benefits to the Enterprise are to be realized by implementing the Lean manufacturing philosophy.

Process -

2-1. Select Initial Implementation Scope - The boundaries of the products/processes to be transitioned to Lean need to be defined as to the point upstream where the physical transformation of material into a product begins and downstream where the product is received by the customer. The order to delivery information loop that controls the production process from order receipt to delivery also needs to be defined. Too broad of an initial project area will complicate and stretch out the transition process. Best results are obtained by breaking up the areas for transition into practical and manageable steps while still retaining the overall systematic approach and plan.

2-2. Define Customer - Lean focuses upon meeting the needs of the ultimate user of the product. Waste enters into the production system when requirements of internal or intermediate customers are mistakenly taken for that of the ultimate user of the product. A prerequisite to correctly defining which operations are value-added and which are non-value-added is a clear definition of who this ultimate customer is.

2-3. Define Value - Quality, Schedule, and Target Cost - Care must be taken to separate the ultimate customer's definition of value from that of other functional areas of the business as well as other business organizations in the overall product flow. Value needs to be defined in terms of their expectations of the product. This definition can be broken down in different ways, but almost always includes as minimum elements: product quality, delivery schedule, performance and meeting target cost.

Output - The product, customer, and value all defined so as to allow the distinction between value added and non-value added operations.

Phase 3 - Identify Value Stream

Introduction – The value stream map or chart serves to identify when and where value is being added and where waste is occurring along the entire path of the product. Value stream mapping provides a means to easily recognize and communicate what is taking place thus allowing team members to more readily target waste elimination. Value stream mapping is an iterative step in the transition to Lean process and is an important part of the continuous improvement process. There are many simple and effective ways for recording the value stream, sophisticated computer simulations or mathematical models are not required.

Input - A value definition for the product being transitioned to a Lean production philosophy.

Process -

3-1. Record Current State Value Stream - The purpose for constructing a current state value stream map is to allow the entire production system to be documented in a simple manner that shows where the waste in the production process is. The map is usually one page that shows the entire flow from order receipt to final delivery. Information from both metric data and observation is collected and added to the map that will help to show where there is waste in the production process that can be eliminated. Maps are often developed at different levels of detail to help further meet this objective. The map is used in the transition planning to prioritize projects based upon potential savings.

3-2. Chart Product and Information Flow - Following the product as it moves through the production system and seeing what happens to it is very revealing. The amount of time a product is sitting idle should be recorded as well as the distance it travels when in motion, the times it is moved or positioned, and the amount of rework should all be recorded. The amount of time spent collecting and submitting data on the product's location, time charging, and other information recorded should be measured. This information may be added to the current state value stream map for analysis during the design phase.

3-3. Chart Operator Movement - The operator's actual movements in the shop are traced over a layout of the facility to create a spaghetti chart. Analysis of the chart will show wasted actions and movement that can be usually removed from the process by standardizing operations and/or simple rearrangement of the work area. A mechanic in an assembly operation is generally the one who adds value to the product and therefore his movement around the shop should be minimized. However, in fabrication operations it is the machine that usually adds value to the product and the mechanic should not be linked to it. In either role the mechanic's activity should be focused on facilitating what ever will aid in getting value added to the product faster.

3-4. Chart Tool Movement - A similar spaghetti chart outlining the movement of tools in the shop with a subsequent analysis will show additional opportunities for the removal of wasted motion from the operation.

3-5. Collect Baseline Data - Performance of the current production system provides a baseline to measure progress and develop a business case justification for any improvement expenditures. Data on direct and indirect costs, production cycle and throughput time, and quality and schedule performance should be documented.

Output - A value stream map that shows the entire information and production process as a system with measures of value added and waste for each process.

Phase 4 - Design Production System

Introduction - The concept behind this phase is to do the high level design of the production system. This design must recognize that the implementation will take several stages (Phases 5 and 6). Therefore, the key point in this phase is to consider the system design in total and not to get mired in the details of the implementation. This phase involves less implementation and more planning. It is important to understand where and how the production system will evolve.

Input - The value stream as it exists.

Process -

4-1. Develop a Future State Value Stream Map - Using a system view of the operation determine how you want the system to function. Some key questions are: what type of production system do you want, how do you want to synchronize with your suppliers, how are deliveries going to be made to your customer, and how are you going to coordinate and control your production operation? Each of these questions leads to system decisions that will define the future state value stream. Since our objective is to transition to Lean production operations the future state value stream should incorporate Lean concepts that ensure close coordination with suppliers, smooth flow of parts and assemblies through the operation, and all linked by the customer demand rate.

4-2. 2. Identify Takt Time Requirements – Although the formula for determining takt time is relatively simple (see the formula below) there are other factors that must be considered.

Takt Time = Available Time / Average Daily Demand

The first step is to determine the maximum output that the production system should be designed to handle (i.e. its highest capacity). It is often useful to consider the demand in some period in the past and to forecast the future demand anticipated. Then a minimum takt time can be determined that addresses the highest demand that is anticipated. The demand is often variable; therefore, the idea is to create a system that will work well with many different customer demand rates. The production system must be capable of addressing this variable demand. Therefore, a range of takt times must be designed into the production system that will meet the expected demand. The minimum takt time will establish the maximum capacity of the system and the maximum takt time will establish the minimum capacity of the system. At any point in time the average customer demand will define the takt time needed throughout the facility. This takt time determination must be done for the major components and the final product. If the components of the product are common among several product lines, the demand for each product must be considered in the takt time calculation. Additional information on takt time calculations is provided in Appendix A.

4-3. Review Make/Buy Decisions - After designing the future value stream and determining the production system takt time, it is often necessary to review previous make/buy decisions. Often certain types of parts or assemblies naturally fit the new value stream or a new layout. Therefore, it makes sense to group all like parts or assemblies that can be processed within the production system takt time. This requires the review of previous make/buy decisions to pull in those parts/assemblies that fit the internal value stream and to outsource those parts that do not conform to internal processes or value activities planned.

4-4. Plan New Layout - The key in a new layout design is to ensure that each of the operations can be completed within the takt time. The first step is to review the future value stream to see if present operations have the potential to be improved so that they may be completed in less time. Each operation should be evaluated relative to the takt time to determine if it can be completed within the minimum takt time or not. Those operations that are less than the minimum takt time may be combined with other operations as long as the combined operations minimum takt time is not exceeded. For those operations that are longer than the takt time, some means must be devised to subdivide the operations to ensure that the minimum takt time is not exceeded or parallel processing must be done. The least desirable solution is to plan work-in-process inventory and lot size production to de-couple operation steps that exceed the minimum takt time. To improve the chances for success in the next phase, the new layout should be situated as much as possible to allow contiguous one-direction flow through the production system.

4-5. Integrate Suppliers - Suppliers should be a major consideration in the future value stream. With the production system takt time and the layout defined, the suppliers need to be synchronized with the production system. Therefore, each of the suppliers should be integrated into the production system with the guiding principle that they be able to deliver their products to support the production system's capability to meet the minimum takt time. There are multiple ways to do this integration but the production system design should consider the systems that will provide the necessary information to the suppliers to make it possible for them to conform to this new system design. This integration requires two-way communication between the supplier and the customer.

4-6. Design Visual Control System - To enable a Lean production system, it must be as simple an operation as possible. One method to do this is to design easily understood visual control systems that communicate production system control. In fact, the best production system is one that controls itself. By designing visual means of control, everyone within the system may take actions to keep the production system in control. Therefore, this step requires not only the physical design of visual devices to control the operation but also the education of the workforce (and management) in how the system can be controlled from within.

4-7. Estimate and Justify Costs - This new future state value stream and its production system design will most likely involve investment. his investment must be estimated and justified. Although this sounds straightforward it seldom is. Many of the cost savings are not easily quantified and present accounting systems and their metrics often penalize Lean activities. Therefore, the senior level management buy-in that was obtained earlier is useful to help guide and shape this justification process. It is helpful to address the system effects and to characterize the system improvements as the measure of effectiveness that will be most meaningful.

4-8. Plan TPM System - Since the production system is being designed to improve flow and minimize waste, it is important those production resources are available when they are needed. In this new production system design, there is no (or little) safety buffer to alleviate system perturbations. The way to ensure that unplanned perturbations are avoided is to implement a Total Productive Maintenance (TPM) System. This system will ensure that production resources are monitored and systematically maintained so that there are no or a minimum number of unplanned production disruptions. The system design phase is perhaps the best time to plan for the implementation of a TPM system.

Output - A production system design that is ready for incremental implementation

Phase 5 - Implement Flow

Introduction - This phase marks the conversion from a batch and queue type of operation to cellular type of operation. In this phase individual cells are established in the production system to implement flow within those cells. The principles of this phase are applicable to both fabrication and assembly.

Input - A high-level Lean production system design and implementation plan.

Process -

5-1. Standardize Operations - Standardized operations means everyone in a work team performs a given task in the same "best" way to optimize the process flow. Personal, unilateral innovation is not allowed. Continuous improvement (kaizen) is encouraged and if a better way to do the work is discovered, it is presented to the work team and leader for evaluation and if judged to be an even better way to do the task it may then become the new standard. Standardized operations lead to standard times, which allows work to be synchronized and also provides metrics by which work can be continuously monitored and improved.

5-2. Mistake Proof Processes - Product defects are wasteful and if not discovered early in the manufacturing process they can lead to unneeded cost and customer dissatisfaction. One of the principles of Lean is that it is not acceptable to produce even a small number of defective goods. Mistake proofing methods are simple in nature and avoid inadvertent errors by using such things as locating guides on the part or the tool, limit switches to detect errors, counters, and checklists. These devices function to shut down, control, or provide a warning to the manufacturing process.

5-3. Achieve Process Control - A process that is under control is statistically predictable as to its outcome. Process variations result from one of two types of errors: special causes or common causes. If the process has no special cause present, the process is said to be in statistical control, or stable. The average and limits of variation are predictable with a high degree of confidence over the immediate future. In the absence of statistical control, no prediction is possible. "Process capability" is often what we mean when we say process control. Process capability is a way of measuring product or process variation against a set of design or customer specifications. Two common capability indices are Cp and Cpk. Cpk is a preferred capability that takes into account all three factors of process centering, process variation, and the tolerance of a specification. "Achieving Process Control" can also mean consistency about the production system performance measures such as throughput time, on-time delivery, quality, equipment reliability, etc.

5-4. Implement TPM - TPM stands for Total Productive Maintenance. The focus of TPM is on five major elements: maintenance prevention (avoidance of breakdowns), predictive maintenance (being able to predict impending breakdowns i.e. using sensors, etc.), improvement maintenance (fix the problem so it doesn't recur), preventive maintenance (routine maintenance to avoid breakdown), and 5 S maintenance by equipment operators (e.g. cleaning so that oil leaks show, replacing filters, daily inspection of equipment, recognizing early signs of trouble). TPM is essential for the successful implementation of machine intensive, just-in-time production systems.

5-5. Implement Self-Inspection - Self-inspection is based on the fundamental principle of self-discipline. Self-inspection implies that the operator has been properly trained, has the proper tools to inspect his work, is conscientious in his work, and has the integrity to refuse to let discrepancies propagate downstream from his workstation. Not only is worker discipline necessary but worker-management interactions must be designed in a way to ensure integrity of the self-inspection program.

5-6. Eliminate/Reduce Waste - All the principles of Lean are designed to eliminate or reduce waste. Taiichi Ohno classified waste into 7 categories: overproduction ahead of demand, waiting, transport of materials, overprocessing, inventories more than absolutely required, unnecessary movement by employees, and production of defective parts. Inherent in this concept is continuous process improvement where processes are continually reviewed to systematically reduce waste.

5-7. Cross Train Workforce - Smooth and continuous flow of work often depends on how well the workforce is cross-trained to support the total process flow. Adjacent workers picking up some of the work content of the more heavily loaded workstation can usually smooth slight variations in workstation work content. Cross training brings the ability to switch from one task to another, thereby relieving stress, boredom or tiredness of the worker. Cross training provides appreciation of the contribution of others and builds team spirit. Consolidation of job classifications may be a necessary prerequisite to cross-training.

5-8. Reduce Set-up Times - Set-up time is categorized as internal set-up time or external set-up time. The internal setup time is that setup time which requires the machine to be stopped; external setup time is that setup time that can take place while the machine is running. The most important concept of setup time is to convert as much of internal setup to external setup. Until set-up time, transport time, work order processing and other batch related items of time waste are reduced, lot size reduction usually only adds to total cost. However, as set-up time is reduced, lot size can then be appropriately reduced with its corresponding reduction of finished and intermediate product inventory.

5-9. Implement Cell Layout – A proper cell layout is critical in attaining flexibility in the number of workers within a workshop to adapt to demand changes. The recommended layout for a cell is the counter-clockwise flow direction "U-turn" layout. In this configuration the entrance and exit of a line are near the same position. This layout structure allows workers to easily see unbalanced operations and to take action to provide the necessary support for keeping the flow of work uninterrupted; it also allows regions or areas to be developed for specific worker operations and walk patterns.

Control of product flow within the cell is, ideally, accomplished with what is known as single-piece, or one-piece flow. That is, once an item (e.g. a part) has begun processing within the cell it does not stop until it exits the cell. In machine-based cells the worker often has a walk pattern that allows him to unload a part from a machine, reload the machine with the next part, start the machine, and then proceed on his walk pattern while the machine continues to work. Typically, he will tend several machines on his walk pattern and will have the work balanced such that when he returns to the first machine it will have just finished the first processing operation. He then continues to repeat his previous pattern. Critical to the success of single piece flow is the use of standard work packages using balanced work content to create equal time intervals (cell takt time) at each work station. This allows each operation to be synchronized with each of the other operations and eliminates the waste of waiting for an operation to complete. Other types of cells may not require a walk pattern for any of the workers but the principles are essentially the same (for example, where there is such high volume (short takt time) or high work content that it is necessary to have a worker at each station).

5-10. Implement Visual Controls - The concept of visual control is based on the 5S principles with the intent of being able to determine the state of the shop "at a glance". A clean, orderly shop, in the sense of Lean production, allows this to happen. The first two 5S principles divides items in the shop into "necessary" and "unnecessary" classifications. Anything unnecessary is removed from the area (disposed of, surplussed, put in red-tagged storage, etc) and the necessary is made orderly, easy to find, easy to reach, and easy to use and maintain (e.g. shadowing of tools). Shop cleanliness, the third S, is essential to spot problem machines at a glance (e.g. leaking oil), and out of place items. The fourth S, provides for standardizing ways of doing work, cleaning, organizing parts and tools, and provides the way to spot "out of the ordinary" problems and inefficient ways of doing things. In addition to the 5Ss, visual controls also rely on up-to-date, simple posters or signs within the shop to indicate the status of today's production, quality metrics, and progress on continuous improvement. Successful visual controls rely on the fifth S of self-discipline for sustaining the overall effort of the 5Ss and keeping current the shop statusing charts. Another aspect of visual control is the ability to bring resources to bear quickly whenever there is a production problem. This often entails a way to signal that there is a problem and an easy way for all resources to know where the problem is located. (Note that many organizations have added a sixth S for safety.)

Output - Areas within the production system have implemented processes to ensure that production flow has been achieved. In this state individual areas have managed to reduce a significant amount of waste.

Phase 6 - Implement Total System Pull

Introduction - In this phase the intent is to link the various flow operations that have been established in miniature throughout the production system and to establish pull operations across all the processes/operations /cells within the entire production system. This often equates to linking individual cells within the production system and suppliers with a pull type system. Successful completion of this phase results in a just-in-time type of pull production system that starts with suppliers and ends with the final customer. See definition of pull in the definitions section.

Input - A production system that has implemented flow operations principally in individual cells within the production system.

Process -

6-1. Select Appropriate Production System Control Mechanism - A production system plan was developed in Phase 4, and in Phase 5 efforts were made to remove waste from the system to achieve predictable output. With the help of the workforce, as simple a system as possible should be implemented to control the flow of parts and assemblies in the production system. We use the word 'control' instead of 'plan' to emphasize that the system should be as self-regulating as possible thereby reducing the time constant of reaction, and conveying information upstream and downstream. More sophisticated systems may be necessary in certain circumstances but often a simple card, cart, or bin visual system is very effective. One method that is both visual and effective is a kanban system. The prerequisites for a kanban type system are: (1) a pull system mentality, (2) a system with a predictable output, and (3) standard work-in-process inventories. Appendix B gives some guidance in developing a kanban system. Other possible control mechanisms could be Constant Work in Process (CONWIP), scheduling policy systems, MRP/ERP systems or hybrids of several different mechanisms.

6-2. Strive for Single Item Flow - In order to achieve a pull system, product components, subassemblies and final products must flow through the production system as if they were a single item and linked to the demand rate specified by the customer. This single item can be a kanban container, a small lot or a single piece. The objective is to reduce the lot size as much as possible with the ultimate goal of single piece flow. The delay time built into large lot size processing is incompatible with a pull system. To reduce the lot sizes, setup times must be reduced to allow single product items to flow through the production system. Where single item flow can be achieved, the throughput time is drastically improved, quality is usually improved because defects are recognized earlier in the process, and inventory is reduced because there is a lower work-in-process level and finished products are rapidly accepted by the customer. Single item flow implies that products are not worked on until the downstream process demands those products.

6-3. Level and Balance Production Flow - Key to implementing a pull system is the leveling of the production to match the mix of products demanded by the customer over a specific time interval. In many cases, this process of leveling production must be a specific objective of the senior managers in the production system. It is often useful to implement level production first in the assembly operations to ensure that the right mix of products is made at each customer demand interval. With the mix of products matching the customer demand, the next step is to ensure all the preceding production operations have a consistent cycle time and that this cycle time is less than or equal to the takt time determined in the production system design phase. This often entails linking the various cells ultimately to the final assembly operations. Instead of planning production, the level and balance concept allows control of the production system. One way that is useful in leveling the production on a daily basis is the use of *Heijunka*. In this system the daily demand is ordered in a box to pull products of the right mix through the system. In essence, this *Heijunka* box performs the sequential planning and control function for the production system. It plans the sequencing needed to satisfy the customer mix demand and it controls the introduction of work to the production floor. Therefore, at the conclusion of this step, each operation would be done at or less than the takt time and the mix of products desired by the customer would be completed within the interval that the customer demands. One should note that customer requirements are not being satisfied from finished goods inventories in this system.

6-4. Link with Suppliers - Although these steps imply an order, the linkage with suppliers should be an ongoing activity. Suppliers should be encouraged to develop a system that links to the prime just as the prime is developing a system to link to their customer. Therefore, suppliers should determine their takt time requirements and ensure they can provide parts or subassemblies to the prime, as the prime needs them in their operations. Timing is not the only consideration, however. This linkage should include part/assembly configuration and information. The production systems between the supplier and the prime should be synchronized to ensure that each system produces exactly the same sequence of parts/assemblies that are demanded downstream. Often this linkage requires a method of sharing information about the production long-term requirements, production requirement changes and short term production scheduling. With the information available the production systems of suppliers and primes may be coordinated to control production.

6-5. Draw Down Inventories - As both the internal and supplier systems implement Lean practices, inventory stocks may be slowly depleted. If inventory is drawn down too quickly the production operation may be disrupted because demand is reduced. However, if the excess inventory is slowly drawn down over time, the new production system can transition more easily. In fact, the transition period may be assisted by using this excess inventory to compensate for reduced productivity while systems are being changed.

6-6. Reassign People - As the production system is implemented, there will be changes that will impact the workforce. It is important to deploy these trained and experienced people to other areas so that they can teach others about this new system. It is here that the foundational preparatory work done in Phase 1 to addresses workforce changes will be most beneficial. To the maximum extent possible people should be reassigned to other areas in the company.

6-7. Re-deploy/Dispose Assets - Just as people will need to be re-deployed, so too will excess assets. Often even simple, less complex resources can be re-deployed for use in special circumstances. Only those assets necessary should be retained in areas that have accomplished the Lean transition. All excess assets therefore should be re-deployed or disposed. When excess assets are disposed of, additional floor space can be identified for new business opportunities.

Output - A production system that matches its production to what the customers demands at the rate, quantity and mix that is demanded.

Phase 7 - Strive for Perfection

Introduction - This phase provides for continuous improvement and feedback of lessons learned along the Lean journey. The various Lean techniques and tools implemented in earlier phases are repeated and refined taking the improvements to the next level. The organization matures from directive to collaborative to empowered. Metrics are reassessed and revised or replaced as necessary to ensure that they are meaningful indicators of the production processes and the overall health of the Lean implementation. The outputs from this phase may feed back into any and all other phases as the Lean transition improves the competitive position of the production operation and the enterprise.

Input - Since Phase 7 is unique in that the actions shown may take place at any and at numerous times concurrently with Phases 2 through 6, the minimal inputs are the leadership commitment and the Lean implementation roadmap.

Process -

7-1. Team Development – Team development includes technical development to keep pace with new product and process features, organizational development to empower the work force to contribute at all levels, and Lean process development to expand upon the tools and techniques being applied. Classroom, workshops, and on-the-job training events conducted with natural workgroups help foster team spirit and can be tailored to the specific production processes being utilized by the team. The roll of the team leader, manager, or supervisor expands to include teaching, coaching, and facilitating.

7-2. Optimize Quality - Quality is a perquisite to overall world class status and tightly correlated with customer satisfaction, market share, and cost. Capturing and reporting DPMO (Defects Per Million Opportunities), PPM (Parts Per Million), first pass yield, or process robustness (sigma) is the first step to continuous improvement. Measuring processes with any of the aforementioned metrics allows for base-lining current process capability, analyzing improvement opportunities, establishing stretch improvement goals, quantifying improvements realized, and controlling process variability. Attainment of increasing quality levels also fosters pride in workmanship. Phase 6 (Implement Pull) mandates quality or production will stop. Six sigma is a statistical measurement tool and also a trademark program developed by Motorola and applied more generally by GE. Emphasis is on processes which yield sustained results.

7-3. Institutionalize 5S - The 5Ss are the foundation for Kaizen and implementing visual production controls. The 5Ss are defined as follows:

Simplify or Sort - Remove unnecessary items from the work area

Straighten or Simplify - Organize tools, accessories, and paperwork
Scrub or Shine - Clean, Repair, and keep it clean
Stabilize or Standardize - Establish and maintain controls and standards
Sustain or Self-Discipline - Strive for continuous improvement

Institutionalizing the 5Ss will allow for higher productivity and a safer and more pleasant workplace. (Note that many organizations have added a sixth S for safety.)

7-4. Institute Kaizen Events - Continuous incremental improvement, Kaizen, is a fundamental tool for Lean implementation. A Kaizen event starts with mapping (flow chart & spaghetti diagram) the current “As-Is” process and quantifying the processing times and distances traveled by people and parts. Next, non-value added activities are identified by assessing the current process with tools such as Brainstorming and “The 5 Whys”. This assessment, along with applying 5Ss and visual control principles, defines the improved “To-Be” process. These improvements are implemented and the new improved process becomes the baseline for future Kaizen events.

7-5. Remove System Barriers - Legacy policies, procedures, and computer systems often create barriers to Lean implementation. When these barriers are encountered, the origins of the legacy process should be determined. Unless the legacy process can be traced back to federal, state, local, or corporate requirements, the need for the policy, procedure, or computer system should be questioned and changed, if necessary, to allow for Lean implementation. Enterprise level resources should address the federal, state, local or corporate barriers.

7-6. Expand TPM - Total Productive Maintenance (a LEM best practice) provides a comprehensive, life cycle approach to equipment management that minimizes equipment failures, production defects, and accidents. Planned in Phase 4 and initially implemented in Phase 5, TPM enables manufacturing costs associated with variability in both product quality and production schedules to be reduced. Phase 7 tracks the incremental implementation of TPM to achieve a level of equipment reliability that allows for pull and single piece flow (Phase 6).

7-7. Evaluate Against Target Metrics - Target objectives (metrics) were established in Phase 1 to challenge continuous improvement and steer the Lean implementation. Tracking and periodic review of these metrics provides assessment of the implementation. The evaluation will determine if mid-course corrections are required or if the metric is no longer adequate.

7-8. Evaluate Progress using Lean Maturity Matrices - Becoming Lean is a considerable and truly never ending journey. Along the way, periodic self-evaluation and/or benchmarking of the organization’s degree of Leanness against a standard or others further along will help to keep the implementation on course. The Lean Maturity Matrix is a tool that is increasingly being used by organizations to both evaluate where they are at today and to provide a vision of where they want to be at some point in the future. The typical matrix utilizes a grading scale according to the degree of implementation of several different major Lean practices.

Output - Just as the inputs to Phase 7 may take place at any and at numerous times concurrently with Phases 2 through 6, the outputs of Phase 7 are incremental, continuous, and generally supportive of the Lean transition process.

Definitions

Terms unique to describing Lean systems and utilized on the Roadmap are defined below. These definitions are taken from the Air Force Materiel Laboratory Industrial Base Information Center.

Balanced Production Flow: A balanced production flow means that every day you produce the exact number of products (or parts) you need in every work cell, right up through the final assembly line. The JIT philosophy states that balance is required for flow and that balance, therefore, is of prime importance, even more important than speed. All operations produce at the same cycle time, this is sometimes called the takt time. A balanced production system means that all components are designed to operate at the pace of customer demand.

Edward J. Hay, The Just-In-Time Breakthrough – Implementing The New Manufacturing Basics, New York, New York, John Wiley & Sons, 1988

Note: It is suggested that interested readers review the source materials, and other readily available literature on this subject, for better comprehension. This term does not lend itself to a simple narrative definition.

Cycle Time: This term is very confusing because it is used in multiple ways. The definition of cycle from the Merriam Webster's Collegiate Dictionary is "an interval of time during which a sequence of a recurring succession of events or phenomena is completed". In Monden and other authors cycle time is synonymous with takt time. However, others view cycle time as the time required to produce one product by a machine, station and/or operator. It is the time required to repeat a given sequence of operations or events.

Yasuhiro Monden, Toyota Management System - Linking the Seven Key Functional Areas, Portland Oregon, Productivity Press, 1993
Edward J. Hay, The Just-In-Time Breakthrough – Implementing The New Manufacturing Basics, New York, New York, John Wiley & Sons, 1988

5S: 5S represents five Japanese terms perceived by many to represent the fundamental elements of a Total Quality Management (TQM) approach:

- Seiri (organization)
- Seiton (neatness)
- Seiso (cleaning)
- Seiketsu (standardization)
- Shitsuke (discipline)

The English Translation:

- Simplify or Sort - Remove unnecessary items from the work area
- Straighten or Simplify - Organize tools, accessories, and paperwork
- Scrub or Shine - Clean, Repair, and keep it clean
- Stabilize or Standardize - Establish and maintain controls and standards
- Sustain or Self-Discipline - Strive for continuous improvement

Dr. Chao-Hsien Chu, *5S for World Class Manufacturing*, College of Business, Iowa State University
William L. Duncan, *Total Quality: Key Terms and Concepts*, (New York: AMACOM, 1995)

Flow: (Process-oriented flow, flow Kaizen) The objective of process-oriented flow is to convert functional layouts of machines in the factory into a series of processes, based upon the production of families, or commodities. Process-oriented flows are superior to traditional functional layouts since they reduce travel distance, required floor space, and total throughput times. They also lend support to conversion of operations into cellular manufacturing since workstations are in close proximity and materials can move easily between them.

William L. Duncan, *Total Quality: Key Terms and Concepts*, (New York: AMACOM, 1995)
Wallace J. Hopp and Mark L. Spearman, *Factory Physics, Foundations of Manufacturing Management,* (New York: McGraw-Hill, 1996)

Just in Time (JIT): JIT is an enterprise-wide operational philosophy and an operational strategy of waste elimination, the underlying principle of which is anything that does not add value is eliminated or minimized to the greatest possible extent. The roots of JIT extend deep into Japanese cultural, geographic, and economic history. JIT is commonly used to describe a stockless production manufacturing approach where only the right parts are completed (and/or delivered by suppliers) at the right time. JIT represents four requirements: (1) produce at the right time, (2) at the right pace, (3) in the right quantity and (4) with the right quantity.

William L. Duncan, *Total Quality: Key Terms and Concepts*, (New York: AMACOM, 1995)
David W. South *Encyclopedic Dictionary of Industrial Automation and Computer Control (Just-in-Time JIT) (New Jersey: Prentice Hall, 1995)*
Editor: Nigel Slack, Warwick University, *The Blackwell Encyclopedic Dictionary of Operations Management*, (Great Britain: T. J. Press, 1996)
Wallace J. Hopp and Mark L. Spearman, *Factory Physics, Foundations of Manufacturing Management,* (New York: McGraw-Hill, 1996)
Dave Cochran and Dan Dobbs

Kaizen: Kaizen is a Japanese word for gradual, unending improvement. A continuous improvement strategy, typically achieved through incremental improvements and involving everyone from top management to supervisors and workers. A process that has its roots in the Toyota Production System. The underlying assumption is small improvements, continuously made to a process, will lead to significant positive change over time.

Masaaki Imai, *KAIZEN: The Key to Japan's Competitive Success,* (New York: McGraw-Hill, 1986)
Melissa Larson, Senior Editor, *Five days to a better process - Are You Ready For Kaizen?*, (Quality Magazine, June 1998)

Kaizen Event: See Kaizen. A Kaizen Event (Blitz) is a short-term, concentrated, assault on workplace wastes and inefficiencies carried out, typically, by a diverse, multi-functional team. The effort might last anywhere from a few hours to a few days, or up to 30 days for very complex effort.

Numerous companies are using this form of rapid improvement to streamline operations. They use it to:

Reduce non-value-added activities

Streamline parts, people and information travel within a process

Reduce cycle time, flow time and lot size

Reduce set-up times

Reduce work-in-process inventories

Reduce floor space requirements.

Realize improvements in: quality, safety, environmental, and 5S issues.

www.hpmconsulting.com/

Kanban: Kanban is a Japanese term meaning "card," that is, visible records. It is an inventory replenishment system associated with JIT that was developed by the Toyota Company. It is characterized by an order point scheduling approach which uses fixed lot sizes of materials in standard containers with the cards attached to each. Material reorder is triggered at the last minute, when the lot of material is moved to the point of use.

James W. Cortada and John A. Woods*, McGraw-Hill Encyclopedia of Science & Technology – 8th Edition, (New York: McGraw-Hill, 1995)*
Steve F. Krar, Editor in Chief, *Illustrated Dictionary of Metalworking and Manufacturing Technology* (New York: McGraw-Hill, 1999)
David W. South, *Encyclopedic Dictionary of Industrial Automation and Computer Control (Just-in Time JIT) (New Jersey: Prentice Hall, 1995)*

Level Production Flow: All operations make the quantity and mix of products demanded by the final customer within a given time interval. Level production smoothes the demand for parts through the manufacturing system and reduces the amount of inventory that must be maintained to meet customer demand.

David Cochran and Dan Dobbs
Hiroyuki Hirano, Editor-in-Chief, JIT Factory Revolution – A Pictoral Guide To Factory Design Of The Future, Portland, Oregon, The Productivity Press, 1987
Edward J. Hay, The Just-In-Time Breakthrough – Implementing The New Manufacturing Basics, New York, New York, John Wiley & Sons, 1988

Note: It is suggested that interested readers review the source materials, and other readily available literature on this subject, for better comprehension. This term does not lend itself to a simple narrative definition.

Maturity Matrix: Maturity matrices establish descriptions of process maturity ranging from ineffectual (level 0 or 1) up to the ultimate level of performance (typically level 4 or 5). Each row in the matrix represents a different process or element being assessed. The matrices are useful in articulating levels of maturity, assessing current levels of performance, and establishing goals for improvement. One example is provided in Figure 3. Another example is the Key Characteristic Maturity Model developed by the Massachusetts Institute of Technology (MIT) Key Characteristic (KC) Group in 1997. The Maturity Model is based upon the results of benchmarking fifteen (15) member companies and observing the different levels of success in KC implementation. The Maturity Model entails twenty-two (22) KC practices in four (4) categories and functions as a self-assessment tool for companies wishing to identify what KC "maturity level" they have achieved regarding those KC practices, i.e., a measure of progress towards becoming Lean. The model identifies four (4) independent "maturity levels":

Level 0: KC practice is not used at all
Level 1: KC practice is called "Reactive"
Level 2: KC practice is called "Semi-Proactive"
Level 3: KC practice is called "Fully-Proactive"

Lean.mit.edu

See also the SEI web site at Carnegie Mellon University

Note: It is suggested that interested readers review the source materials for better comprehension. This term does not lend itself to a simple narrative definition.

Pull: Pull refers to a two sub-system linkage in a supply chain. The producing operation does not produce until the standard work in process between the two sub-systems is less than the set point. When the standard work in process is below the set point, this condition signals the need to replenish. Information flows in the reverse direction from product flow to signal production by the upstream cell or manufacturing process.

Editor: Nigel Slack, Warwick University, *The Blackwell Encyclopedic Dictionary of Operations Management*, (Great Britain: T. J. Press, 1996)
William L. Duncan*, Total Quality: Key Terms and Concepts*, (New York: AMACOM, 1995)
Wallace J. Hopp and Mark L. Spearman, *Factory Physics, Foundations of Manufacturing Management* (New York: McGraw-Hill, 1996)

Push: Push is a term used in Planning and Control in Operations to indicate the direction of the flow of information in the system which causes materials to be moved and activities to be undertaken. In a "push" system, material and information flow in the same direction through the value stream. For example, each work center has responsibility for sending work to the succeeding part of the operation. The work centers "push" out work without considering whether the succeeding work center can make use of it. Typically, activities are planned centrally but do not reflect actual conditions in terms of idle time, inventory, and queues, for example, that exist on the shop floor. The design is not robust with respect to quality and rate problems. Even the best closed-loop push systems are much less responsive to in-process variation, and therefore much less effective for controlling production and work-in-process than pull systems.

Editor: Nigel Slack, Warwick University, *The Blackwell Encyclopedic Dictionary of Operations Management*, (Great Britain: T. J. Press, 1996)
William L. Duncan*, Total Quality: Key Terms and Concepts*, (New York: AMACOM, 1995)
Wallace J. Hopp and Mark L. Spearman, *Factory Physics, Foundations of Manufacturing Management,* (New York: McGraw-Hill, 1996)

Six Sigma: Six Sigma is, basically, a process quality goal. In statistical terms, "sigma" is a metric used to reflect how well a process is working. It describes the degree of variation in a manufacturing process. Companies operating at a six sigma level of quality would produce only 3.4 defects per million opportunities.

WWW.QUALITYDIGEST.COM/DEC97
WWW.ASQ.ORG/ABTQUALITY/GLOSSARY.CGI
WWW.MINITAB.COM/COMPANY/PRESS
Dave Cochran and Dan Dobbs

Takt Time: Takt is the German word for the baton used by an orchestra conductor to regulate or pace the tempo or playing speed of the orchestra, i.e., to synchronize the orchestra. In conjunction with Lean concepts, it is a goal that must be reached to satisfy demand. Takt Time is the available production time divided by the rate of consumer demand (consumption). For example, if a certain piece of equipment operates 540 minutes a day (9 hours) and the rate of consumer demand averages 1.5 machines per day, the Takt Time for that machine would be 540 divided by 1.5, or 360. This Takt Time would be used to pace or synchronize the rate of production to consumer demand/sales, which is central to Lean and/or JIT manufacturing concepts.

WWW.TBMCG.COM/TECH
WWW.QUALITYMAG.COM/ARTICLES/JUN98
James P. Womack and Daniel T. Jones*, Lean Thinking*, (New York: Simon & Schuster, 1996)
Mike Rother and John Shook, *Learning to See: value stream mapping to add value and eliminate muda (Brookline MA: The Lean Enterprise Institute, 1999)*

TPM: Total Productive Maintenance (TPM) was originally developed as an approach to plant maintenance that combines productive maintenance procedures with total quality control and employee involvement to maximize the utility of productive resources. TPM aims at improving existing plant conditions and at increasing the knowledge and skills of frontline personnel in order to achieve zero accidents, zero defects, and zero breakdowns. The five goals of TPM can be defined as:

- Improve equipment effectiveness
- Achieve autonomous maintenance
- Plan maintenance
- Train all staff in relevant maintenance

- Achieve early equipment maintenance

The concepts can be applied on a company-wide basis, not just on the shop floor.

Masaji Tajiri and Fumio Gotoh, *TPM Implementation*, (New York: McGraw-Hill, 1992)
Nakajima, S., *Introduction to Total Productive Maintenance*, (Cambridge, MA: Productivity Press, 1988)
William L. Duncan*, Total Quality: Key Terms and Concepts*, (New York: AMACOM, 1995)

Value: In general terms, value can be defined as worth in usefulness or importance to the possessor's customer.

Value is a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer.

Only an activity that physically changes the product adds value.

Webster's II New Riverside University Dictionary, Boston, Massachusetts, The Riverside Publishing Company, 1984
James P. Womack and Daniel T. Jones, Lean Thinking – Banish Waste And Create Wealth In Your Corporation, New York, New York, Simon & Schuster, Inc. 1996
Edward J. Hay, The Just-In-Time Breakthrough – Implementing The New Manufacturing Basics, New York, New York, John Wiley & Sons, 1988

Value Stream (Value Chain): A Value Stream is all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (1) the production flow from raw material into the arms of a customer, and (2) the design flow from concept to launch. It represents the chain of activities and processes by which value is added to input resulting in the delivery of products and services to customers. By reviewing the chain, you can identify which activities add value and which add cost. Similarly, the concept of the Value Chain holds that activities in a value chain can be divided into two categories. The first is primary activities, which include inbound logistics, such as materials handling; operations; outbound logistics, such as distribution; marketing and sales; and after sales service. The second is support activities, which include human resources management, company infrastructure, procurement, and technology development. It should be noted that each of the primary activities involves its own support activities.

Mike Rother and John Shook, *Learning to See: value stream mapping to add value and eliminate muda (Brookline MA: The Lean Enterprise Institute, 1999)*
Brian I. Joiner, *Fourth Generation Management* (New York: McGraw-Hill, 1994)
Michael E. Porter, *Competitive Advantage* (New York: The Free Press, 1985)

Value Stream Map: A Value Stream Map is a physical document(s) resulting from a manual process that identifies all the actions (both value and non-value added) currently required to bring a product through the main flows essential to every product. Precisely identifying all the actions necessary to create, order, and produce a specific product and sorting those actions into three (3) categories: (1) those that actually create value as perceived by the customer; (2) those which create no value but are currently required by product development, order filling, or production systems (Type One *Muda*) and so can't be eliminated just yet; and (3) those that don't create value as perceived by the customer (Type Two *Muda*) and so can be eliminated immediately.

Comment: This "mapping" effort should include direct, personal contact with primary customers to determine what they value in the products.

Mike Rother and John Shook, Learning To See – Value Stream Mapping To Add Value And Eliminate Muda, Brookline, Massachusetts, The Lean Enterprise Institute, 1999
James P. Womack and Daniel T. Jones, Lean Thinking – Banish Waste And Create Wealth In Your Corporation, New York, New York, Simon & Schuster, Inc. 1996

Note: It is suggested that interested readers review the source materials, and other readily available literature on this subject, for better comprehension.

Visual Controls: See Kaizen / 5S. Visual Controls are elements of a Kaizen strategy, i.e., 5S. Typically the first steps involve identifying and separating necessary things from unnecessary things in the work environment, labeling those unnecessary things for future disposition (Visual Seiri – typically with red labels), and neatly arranging and identifying the necessary things for ease of use (Visual Seiton – typically with sign boards). Visual Controls means making it possible for everyone to see whether the situation is right or wrong and wherein lies the waste.

Yasuhiro Monden, Toyoto Production System – An Integrated Approach to Just-In-Time, Norcross, Georgia, Engineering & Management Press, 1997
Hiroyuki Hirano, Editor-in-Chief, JIT Factory Revolution – A Pictoral Guide To Factory Design Of The Future, Portland, Oregon, The Productivity Press, 1987

Note: It is suggested that interested readers review the source materials, and other readily available literature on this subject, for better comprehension.

Waste: In terms of a Kaizen strategy, waste or "Muda" (Japanese term for missed opportunities or slack) is essentially the waste of manpower, outputs, money, space, time, information, etc. Toyota, the originator of the JIT concept defines waste as anything other than the minimum amount of equipment, materials, parts, and working time absolutely essential to production. The "seven wastes" are:

Overproduction	Producing too much, too early
Inventory	Semi-finished parts between operations
Transportation	Moving parts
Processing	Unnecessary processing steps
Making Defects	Parts need rework or are scrap
Motion	Unnecessary worker movements
Waiting	Workers waiting for machines or parts

Yasuhiro Monden, Toyota Production System – An Integrated Approach to Just-In-Time, Norcross, Georgia, Engineering & Management Press, 1997

Edward J. Hay, The Just-In-Time Breakthrough – Implementing The New Manufacturing Basics, New York, New York, John Wiley & Sons, 1988

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Ron Milauskas - Textron
Craig Miller - Northrop Grumman
Deborah Nightingale - MIT Lean Aerospace Initiative
Brian Schwartz - Pratt and Whitney
Tom Shields - MIT Lean Aerospace Initiative
Bob Torrani - Textron

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Appendix A
Takt Time Calculations

A production system must be designed to address a range of takt times that will meet a variable customer demand. The idea is to create a system that will work well with many different customer demand rates. As you can see in Figure A1, demand is often variable. The minimum takt time will establish the maximum capacity of the system and the maximum takt time will establish the minimum capacity of the system. At any point in time the average customer demand will define the takt time needed throughout the facility.

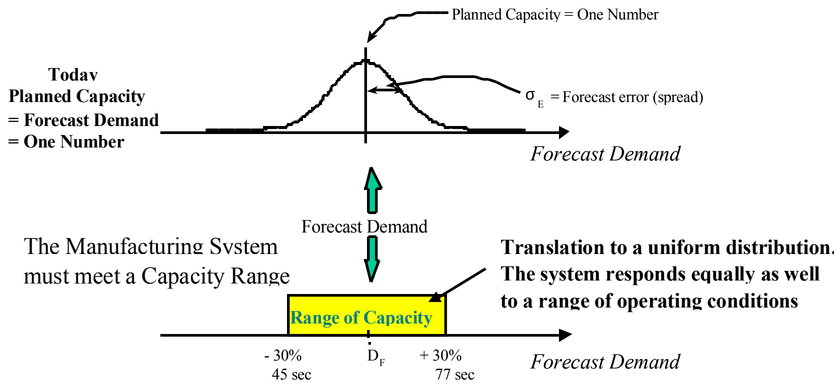

Figure A1: Design Manufacturing System for maximum demand cycle time and range of takt times (Source: Prof. David Cochran, 1996)

Therefore it is useful to convert this distribution of demand over time to a range of takt times that the production system should be able to accommodate. One method is to take the highest demand and add X% to create the operational range. With the highest demand calculate minimum takt time, which is,

$$Takt\ Time_{minimum} = \frac{Available\ Time}{Average\ Daily\ Demand_{withX\%}} \times OEE$$ [1]

Although the following information is too detailed for use in this section, it may assist in future planning or implementation activities. OEE is the overall equipment effectiveness and can be defined as:

$$OEE = Equipment\ Availability \times Performance\ Efficiency \times Quality\ Rate$$

where,

$$Equipment\ Availability = \frac{(Total\ Available Time - Planned\ Downtime) - Downtime}{(Total\ Available\ Time - Planned\ Downtime)}$$

[1] Draft Production System Design Guideline by Prof. D. Cochran, September, 1998, pgs. 36-37.

$$Performance\ Efficiency = \frac{Total\ Parts\ Run \times Best\ Cycle\ Time}{(Total\ Available\ Time - Planned\ Downtime) - Downtime}$$

$$Quality\ Rate = \frac{Total\ Parts\ Run - (Rejects + Scrap)}{Total\ Parts\ Run}$$

Generally, 85% is a world class goal for OEE and X is normally planned at 20-30% over the baseline demand. Available time is usually 7.3 hours per shift for one or two-shift operations and 7.08 hours per shift for three-shift operations; however, this number varies from plant to plant and it depends on the workforce and policies in the company. For example, an aircraft engine company visited was using 6.8 hours as the available time, while an automotive plant was using 7.3 hours.

Appendix B
Kanban Control System Definition

One of the first steps in establishing a kanban system is to implement a system that supports a standard work-in-process inventory. The work-in-process within the operation is dependent on the processing time and the setup of the equipment employed. The standard work-in-process (SWIP)[2] can be obtained by the following formula:

$$Number\ of\ SWIP_{within\,an\,operation} = \frac{\text{Processing } time + load\ /unload\ time}{Takt\ Time}$$

When the processing and setup time exceeds takt time and this time cannot be subdivided or when an out of area operation exceeds takt time a buffer is added to de-couple these operations. This de-coupling mechanism is the number of items in the kanban and the lot size. If each operation is being done at the takt time, a SWIP of one can be used at each of the kanban locations between operations. However, when operations cannot be completed within the takt time and parallel processing is not an option, the kanban and the lot size must be appropriately sized to de-couple the two operations. To ensure that the operation remains balanced the number of parts available over the processing time must be increased so that the number of parts can match the needs of the subsequent operations within the takt time. This is called pitch[3]. The pitch of the operation is given by the formula:

$$Pitch = lot\ size\ x\ takt\ time$$

Therefore, the processing time determines the standard work-in-process which in turn must be de-coupled by the pitch between operations. Next the customer's demand cycle time (that pace at which products are being pulled from the system by the customer) must be factored into the system. A container or kanban quantity needs to be available within the customer's demand cycle time therefore, each kanban must be able to be replenished within this demand cycle time. Knowing the takt time, the number of stations, the number of products the customer wants at each demand cycle and the replenishment time (demand cycle time), the maximum lot size can be calculated (see formula below) that will allow this system to function under kanban pull system rules.

$$Lot\ Size_{Maximum} = \frac{Replenishment\ time\ - (Takt\ time\ x\ Container\ Size)}{Takt\ time\ (x\ number\ of\ stations\ -\ 1)}$$ [4]

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[2] Derived from Production System Design and its Implementation in the Automotive and Aircraft Industry by Vicente Reynal, 1998, pg. 127
[3] Draft Production System Design Guideline by Prof. D. Cochran, September, 1998, pg. 34
[4] Derived from the draft Production System Design Guideline by Prof. D. Cochran, September, 1998, pg. 39.

The above information then can be used to implement a visual kanban control system that will meet customer takt time requirements. It must be remembered that a kanban system cannot be achieved unless the buffer sizes and lot sizes are reduced below this lot size minimum.

Production Operations Transition-To-Lean Roadmap

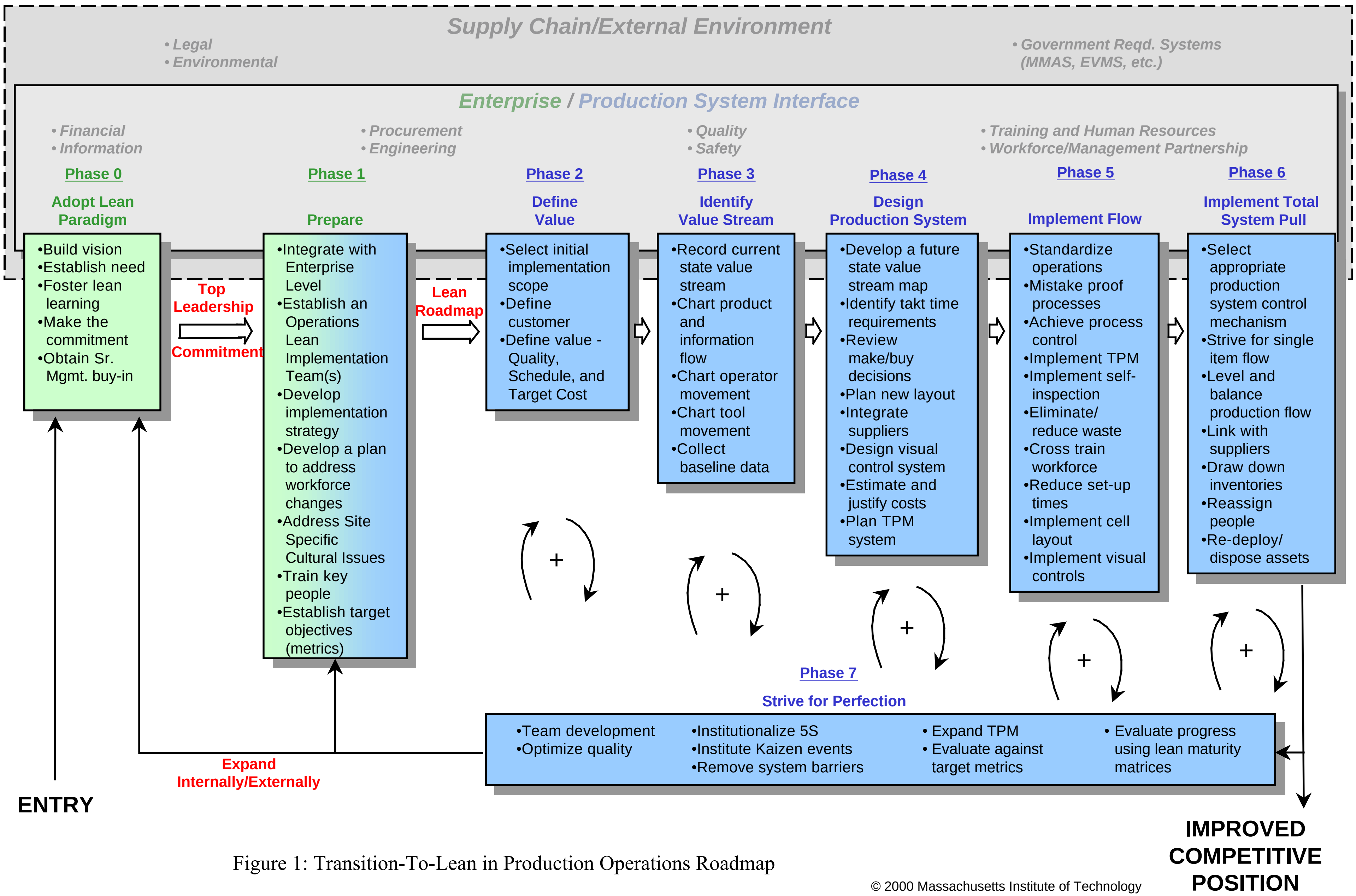

Figure 1: Transition-To-Lean in Production Operations Roadmap

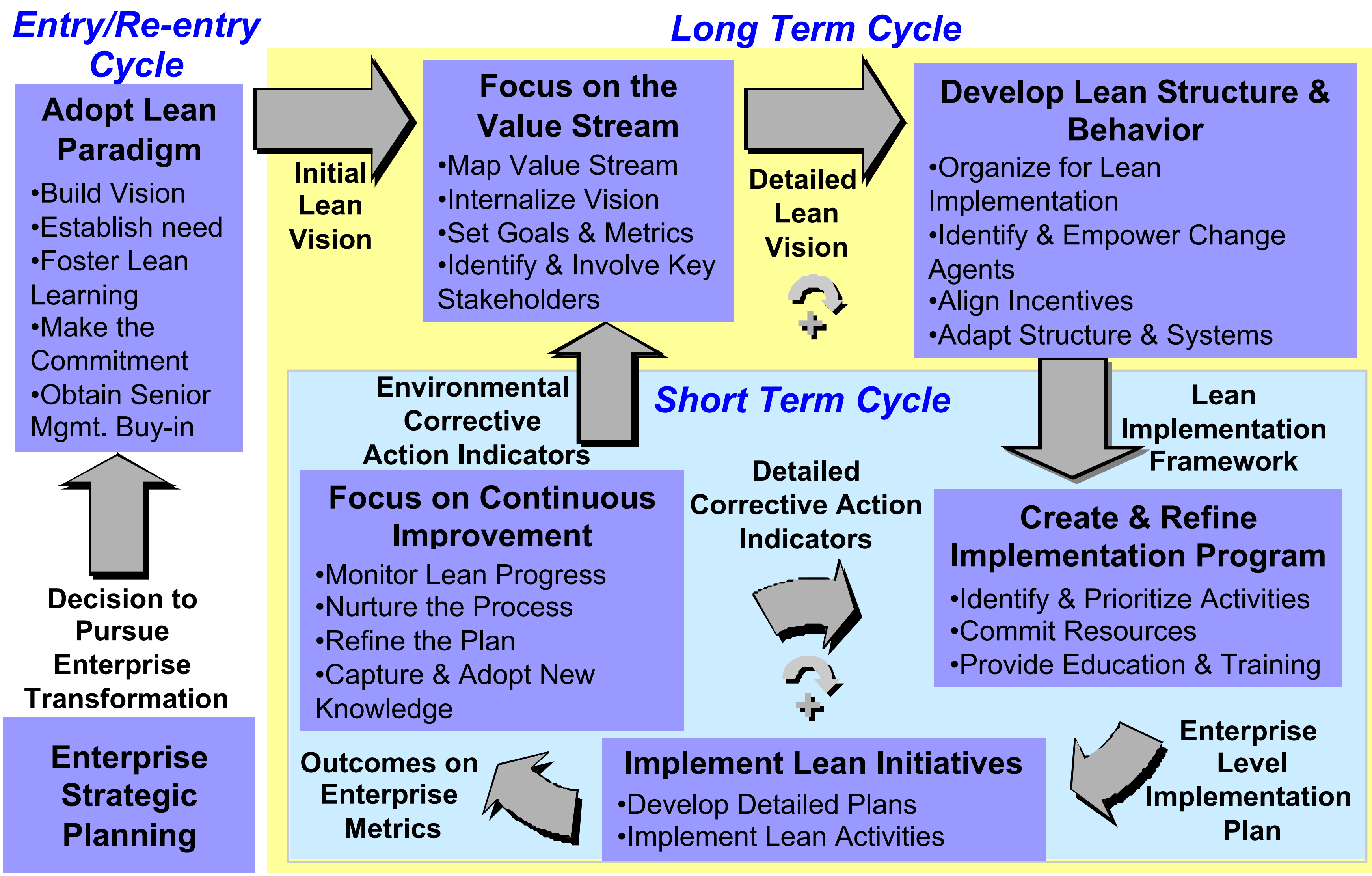

Figure 2 - Enterprise Level Transition-To Lean Roadmaps Structure

Manufacturing System Maturity Matrix (Example)

Practice/Process	Level 1 *Functional as Mass Production*	Level 2 *Partly Lean*	Level 3 *Generally Lean*	Level 4 *Internally Lean, Partly Agile Externally*	Level 5 *Virtual Enterprise*
Use of Human Resources	Narrow job scopes. Strong functional dept boundaries.	Effective training with functional depts	Broad job scopes. Product-based teams across functions. HR policies support teams.	Easily reconfigurable organizations	HR policies support 'real' people working for multiple 'virtual companies'.
Product Definition	Paper drawings. Errors found through trial and error in tooling and production	Some use of CAD. Design includes producibility analysis.	3D digital design flowed to tooling and production. Variability simulation, electronic mockup. Designed in IPD teams.	Shared CAD data and design responsibility with customers and suppliers across many physical locations.	Complete transportability of technical data via industry data standards - PDES, STEP, etc.
Use of Suppliers	Price-based competition. Adversarial relationship	Technical interchange. Incentives for cost reduction and savings sharing	JIT delivery to point of use without receiving inspection. Tiering of suppliers by major commodity.	Sharing of schedule updates electronically	Suppliers identified and contracted quickly through standard contracts, etc.
Quality Practices	Quality improvement through volume learning. Inspect to find bad parts. Customer is final inspector.	Quality function deployment to flow customer rqmnts to product and process KCs	Effective process control and corrective action process. Production self inspects. Mistake proofing	Single quality (ISO based) system	
Production Control	Launch and expedite orders per standard breakbacks for contract lots. Large fabrication batch sizes.	Effective MRP system with finite capacity planning.	Small batches, use of internal pull system. Paperless access to all required information.	Use of pull system between customers and suppliers.	Linked control systems controls flow across several companies.
Business Processes	Separate business process for different customers, military vs. Commercial. Processes producer driven rather than customer pulled.	Heavily interfaced systems.	Single processes for all customers. Heavily integrated systems.	Systems and processes integrated with customers and suppliers.	Contracting, Finance, etc. supports operation of multiple virtual companies.
Facilities and Equipment	Functional layout of processes. Immovable monuments. Excess space and overhead costs. Excess automation.	Effective preventative maintenance. Effective use of process technology.	Smaller, moveable equipment arranged into product flow. Low overhead cost.	Products flow cross company boundaries seamlessly. Equipment and facilities configurable.	Capacity known and managed for a virtual company across many 'real' companies.

From Northrop Grumman Integrated Systems and Aerostructures

Figure 3: Manufacturing Maturity Matrix