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Lean Implementation Considerations in Factory Operations of Low Volume/High Complexity Production Systems

Prepared by:
J. Thomas Shields
Auston Kilpatrick
Michael Pozsar
Luis G. Ramirez-de-Arellano
Vicente Reynal
Mitch Quint
James Schoonmaker

Lean Aircraft Initiative
Center for Technology, Policy, and Industrial Development
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

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Abstract

The researchers of the Lean Aircraft Initiative developed a hypothesized lean implementation model seeking to provide its members guidance on implementing lean transitions in factory operations of low volume/high complexity production systems. The model features four phases: (1) building a lean infrastructure to support lean behavior, (2) redesigning the flow of products in the factory, (3) revamping the operations management and (4) fostering process improvement. An order of implementation is discussed and each phase has implementation steps as well. Following the development of the hypothesized lean implementation model, twelve case studies were used to test the model. This report details the model and analyzes the case studies using the model as a framework. The analysis of the case studies relative to the model indicates that at least three phase implementation steps were used in more than half of the case studies. The order of these implementations is explored also showing that the lean infrastructure phase was initiated first in 86 percent of the studies and the remaining phases followed the order of the hypothesized model in 71 percent of the studies. As a general guide for structuring a strategy for lean implementation, the hypothesized model can be useful tool for members of the Lean Aircraft Initiative to use in the planning and execution of their lean transitions.

Acknowledgments

I would like to acknowledge the participation of Jan Klein, Tim Gutowski and Dave Cochran in the critique and refinement of the hypothesized model presented in this report. The efforts of Jim Schoonmaker and Mitch Quint were instrumental in framing the model from many different conceptual approaches. Michael Pozsar prepared the case studies that used this model to compare lean transitions. Vicente Reynal reviewed previous case studies to compare lean transitions identified in these case studies for comparison with the hypothesized model. Luis Ramirez-de-Arellano and Vicente Reynal helped in assimilating the information for this report. Finally, I would like to thank the members of the Factory Operations Focus Team of the Lean Aircraft Initiative and in particular, Fred Stahl, for reviewing the draft of this report and providing valuable editorial inputs.

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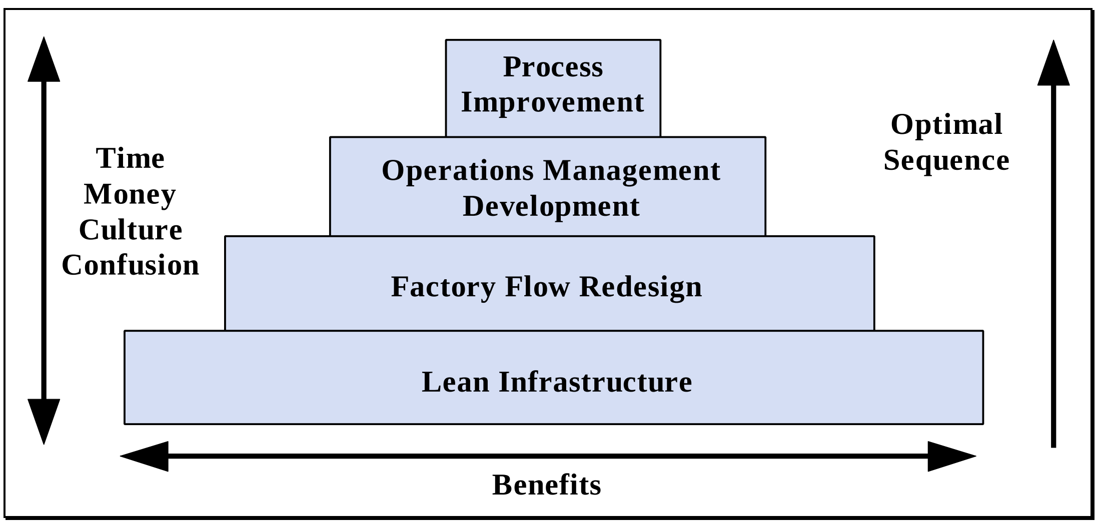
Executive Summary

The members of the Lean Aircraft Initiative (LAI) have long desired to gain some knowledge about how to implement “leanness” into their factory operations. The researchers of the Factory Operations Focus Group investigated those factors that enabled lean transitions to be successful in a factory operations setting. The objective of the focus group was to determine not only what to do but the order in which they should be accomplished.

The researchers developed a hypothesized lean implementation model with the help of colleagues and members of the consortium. The hypothesized lean implementation model was conceived as a tool to test observations of lean transitions that were observed and documented in case studies. The hypothesized lean implementation model (see below) is a four phase implementation process which postulates the optimized order of implementation. In order, these four phases are: (1) building a lean infrastructure to support lean behavior, (2) redesigning the flow of products in the factory, (3) revamping the operations management and (4) fostering process improvement. Each phase has implementation steps as well. A complete list of these steps is provided at the end of this summary.



Following the creation of the hypothesized model, twelve case studies of lean transitions were used to test the hypothesized model. There were three types of case studies used in this test: case studies done specifically to test the hypothesized model (3 of the 12), case studies that had been accomplished prior to the creation of the hypothesized model (4 of the 12), and reviews of other case studies that addressed specific aspects of lean transitions (5 of 12). All the case studies were compared to the hypothesized lean implementation model to determine the steps that were utilized in their lean transitions. These steps were captured using the hypothesized model as a framework. In the case studies, various stages of implementation were observed as the transition progressed. Therefore, the case studies are reported relative to the hypothesized lean implementation model in stages of implementation.

During and after the conduct of the case studies, it was difficult to separate specific implementation steps. Many changes were happening at the same time. This ambiguity was addressed in the model depiction with simultaneous implementations in the same stage. The researchers also found that the steps within a particular phase could not be characterized with normal start and stop types of categorizations. Instead many of the implementations had multiple steps in different phases being implemented concurrently. Many steps continued to be addressed long after another phase of the hypothesized lean implementation model was being addressed. The researchers made their best judgment about the order of initiation of implementation steps. However, it cannot be ruled out that the investigators were biased by the hypothesized lean implementation model. Even with the use of a framework and its definitions, there is significant ambiguity in interpreting the transition steps from observations and there is researcher bias in the categorizing of these results. Despite these shortcomings, we feel that the observations using the hypothesized lean implementation model as a framework does offer some useful insights.

The analysis of the lean infrastructure phase of the hypothesized lean implementation model indicates that at least three phase implementation steps (out of eight) were used in more than half of the case studies. In two cases, the phase was repeated. In the two instances where this phase was revisited increased emphasis was placed on training and achieving a self directed workforce respectively to allow further lean improvements. The specific steps implemented in more than half of the case studies were:

- Identify business issues/goals and develop a strategy
- Identify current and needed skills
- Breakdown stovepipe mentality

The factory flow redesign phase of the hypothesized lean implementation model postulates an order of steps. The analysis of the case studies indicates agreement with this hypothesis in that a predominate sequence of steps was indicated as the following:

- Distribute information
- Group products into families
- Design process layout and simulate flow
- Optimize factory flow and cell linkages
- Redefine and redeploy work tasks

The operations management development phase of the hypothesized lean implementation model was observed in only six of the twelve case studies. In those cases where it was observed, each used at least two of the four steps of the phase. Of the case studies that did the operations management development phase, at least half used the following specific steps:

- Cross-train workers and realign incentives
- Reallocate support resources
- Implement “pull” production systems

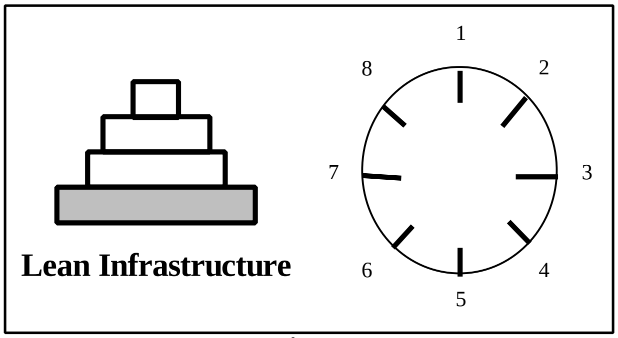
An order to the implementation steps was postulated in the process improvement phase of the hypothesized lean implementation model. Based on the analysis of the case studies, there is good agreement in doing the first two steps (of four): (1) cross-train workers and realign incentives and (2) reallocate support resources.

The implementation sequence for the four phases of the hypothesized lean implementation model using the seven cases that consider enterprise level implementations tends to support the hypothesized model. The lean infrastructure phase was initiated first in 86 percent of the studies. The remaining phases followed the order of the hypothesized model in 71 percent of the studies. The implementation of the lean infrastructure phase and the process improvement phase were most unambiguous usually being initiated first and last respectively. The factory flow redesign and operations management development phases, however, were less definite with all five of the seven cases featuring simultaneous implementations. The extent of the simultaneous implementation of these phases indicates a certain ambiguity to the order of implementation of these two phases. This ambiguity about the order of these two phases was also discussed among the researchers when the hypothesized model was developed. Therefore, the order of the two center phases (among themselves) in the hypothesized model should not be considered order dependent.

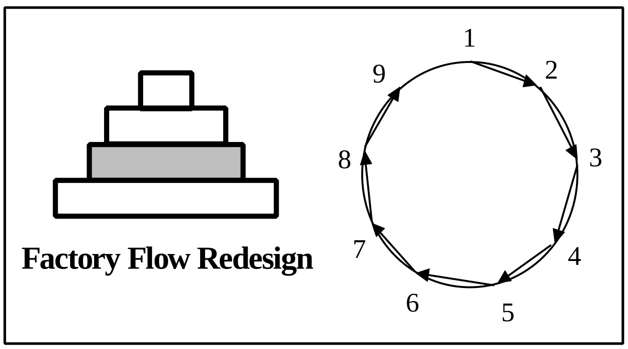
There were several observations from the case studies that were not captured in the hypothesized model. First, it was found that the degree of process ownership by those responsible for a product was a critical factor in successful lean transformations. Secondly, in many of the case studies we found that change did not happen without the leadership of a champion or senior management.

There remain a number of factors that make it difficult to assess the viability of our proposed Lean Implementation Model. First, we do not feel that the evidence based on the case studies is overwhelming. The case study sites themselves may not be characterized as being the best examples available of lean implementations. Therefore, the case studies may not have captured the epitome of a lean implementations. Many of these case study sites however, were sites recognized within the Defense Aircraft Industry as having accomplished small scale lean transitions. The researchers themselves had to make subjective determinations to interpret events at a particular case study site and researcher bias is possible in attributing specific actions to steps in the model.

Despite the shortcomings to this study, we feel that the model offers a general guide for structuring a strategy for lean implementation in the defense aircraft industry. Therefore, we feel that the hypothesized model can be a useful reference for members of the Lean Aircraft Initiative to use in the planning and execution of their lean transitions. However, we acknowledge that the lack of a consistent pattern in our case studies may suggest that there are multiple ways to achieve the same objective.



1. Identify business issues/goals and develop a strategy
2. Perform benchmarking
3. Develop an information technology hardware and software strategy
4. Identify current and needed skills
5. Fill skill gaps with corporate wide training
6. Breakdown stovepipe mentality
7. Assess technology impacts
8. Establish linkages with supplier and customer base



1. Distribute information
2. Group products into families
3. Standardize processes
4. Design process layout and simulate flow
5. Optimize factory flow and cell linkages
6. Redefine and redeploy work tasks
7. Delegate authority and accountability
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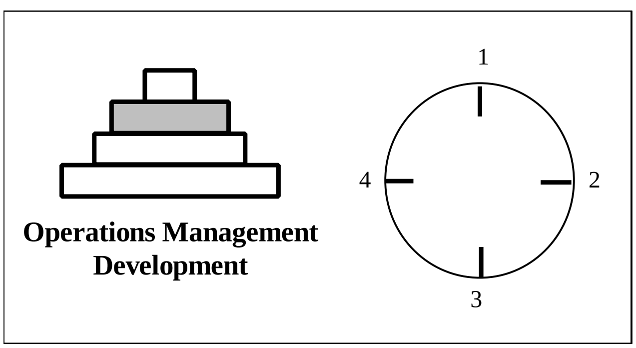
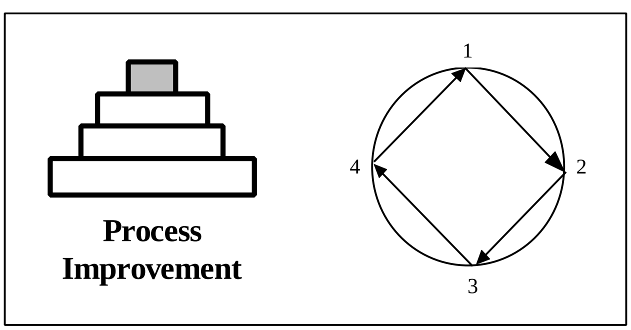


1. Cross-train workers and realign incentives
2. Reallocate support resources
3. Implement manufacturing information systems
4. Implement “pull” production systems



1. Improve process and operations predictability
2. Improve process quality
3. Increase process flexibility
4. Increase process speed

Introduction

The Factory Operations Focus Group of the Lean Aircraft Initiative (LAI) challenged the researchers to investigate those factors that enabled lean transitions to be successful in a factory operations setting. The objective of the focus group was to determine not only what to do but the order in which they should be accomplished.

Six research assistants and four faculty spent four months collaborating to combine their collective experiences into an implementation model. Approximately four distinct versions of the model were developed with each building on the strengths of the prior version. After this phase, a cohesive model was shaped from these various versions. Once this was accomplished, the model was repeatedly reviewed and updated during several initiative-wide research reviews. Therefore, the following description is the culmination of the efforts of not just the factory operations focus group but that of the initiative as a whole.

The hypothesized lean implementation model was conceived as a tool to test observations of lean transitions that were observed and documented in case studies. The hypothesized lean implementation model is a four phase implementation process which postulates the optimized order of implementation. In order, these four phases are: (1) building of a lean infrastructure to support lean behavior, (2) redesigning of the flow of products in the factory, (3) revamping the operations management and (4) fostering process improvement. The implementation sequence attributed to redesigning the flow of products and revamping operations management was challenged by some of our team. To them it was unclear that there was an order to these two phases. We elected to continue and to revisit this order in our conclusions.

Following the creation of the hypothesized model, case studies of lean transitions were used to test the hypothesized model. There were three types of case studies used in this test: case studies done specifically to test the hypothesized model, case studies that had been accomplished prior to the creation of the hypothesized model, and reviews of other theses that addressed specific aspects of lean transitions. The case studies specifically accomplished to test the hypothesized model were most thorough in testing all aspects of the model but were based on only three case studies. Case studies that had been accomplished before the creation of the hypothesized model were valuable but may not have gathered information to compare all layers of the hypothesized model. The reviews of previous theses that addressed limited aspects of a transition revealed good information in a very focused area, but did not indicate the broader interactions necessary for successful enterprise implementation. All the case studies were compared to the hypothesized lean implementation model to determine the steps that were utilized in their lean transitions. These steps were captured using the hypothesized model as a framework.

Factory Operations Hypothesized Model

Introduction to the Model

The model in Figure 1 was developed by the factory operations focus group of the Lean Aircraft Initiative. This model represents the combined input and effort of all members of the team. The purpose of this model is to provide a framework for managers of companies with low volume / high complexity products to not just understand the Lean Enterprise (Depicted by the Lean Enterprise Model - LEM) but to also establish a method for how these concepts can be implemented. It is important to note that this is the team's best estimate of how lean concepts can be implemented on the factory floor based on their cumulative experiences prior to and during LAI. As such, it should be considered a hypothesized model which will change as further case studies deepen our understanding of how these concepts are being implemented in industry. Later portions of this report will begin the process of proving or disproving the hypothesized model.

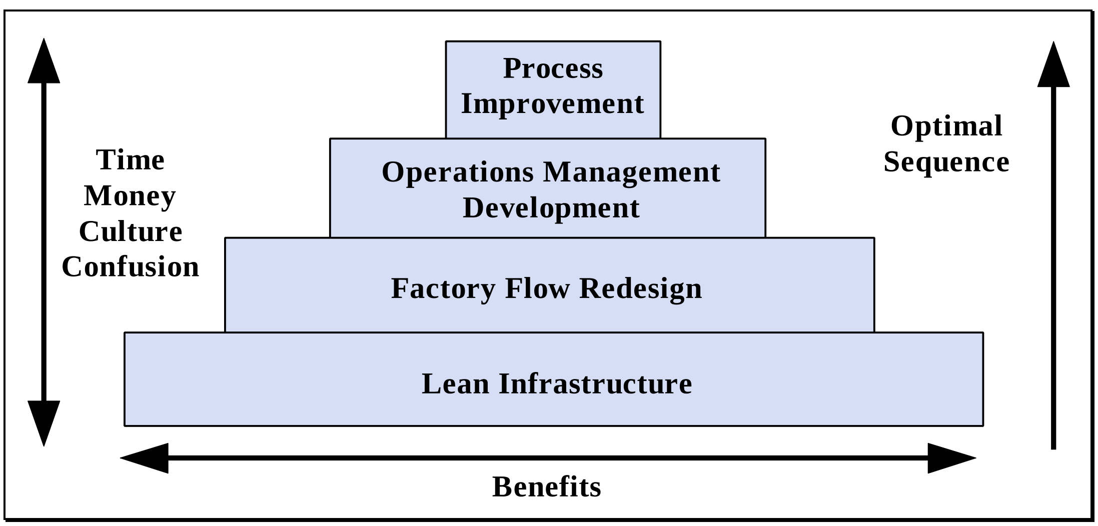


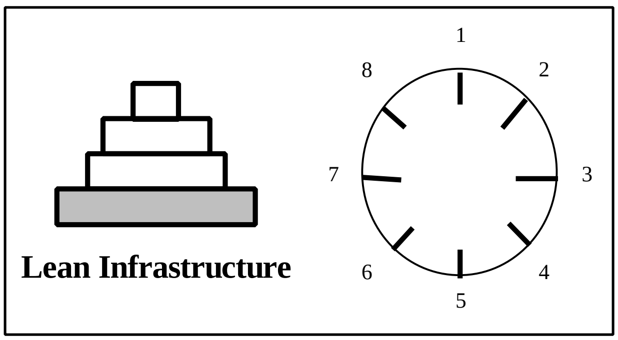
Figure 1: Hypothesized Lean Implementation Model

The model divides the lean implementation process into four phases. These are the Lean Infrastructure, Factory Flow Redesign, Operations Management Development, and Process Improvement phases, later chapters of this report explain these phases in more detail. We will start at the bottom of the model and address the steps inherent in this layer of the model. We hypothesize that some layers have steps that are order dependent and other layers have practices that are order independent.

Each section will show the model under discussion and a clock representation of the practices deemed important within that layer of the model. This clock representation will be used later in the case study section to easily depict the observed practices used in the lean transitions studied. In those layers in which the order of implementation is important, the points of the clock will be connected with arrows.

Implementation Phases

Phase 1 - Lean Infrastructure



1. Identify business issues/goals and develop a strategy
2. Perform benchmarking
3. Develop an information technology hardware and software strategy
4. Identify current and needed skills
5. Fill skill gaps with corporate wide training
6. Breakdown stovepipe mentality
7. Assess technology impacts
8. Establish linkages with supplier and customer base

This phase of implementation represents the foundation on which the other phases are built. The implementation of a lean infrastructure is the first major phase that must be undertaken when attempting a lean transition. A lean infrastructure provides the foundation necessary to maximize the potential benefits of the successful implementation of later phases. Without the development of a lean infrastructure, the organization will not achieve its optimal level of lean manufacturing. For example, if the organization ignores the development of its infrastructure and focuses its efforts on process improvements, it will only be able to optimize the pre-transition potential of process improvements. Essentially, the implementation of a lean infrastructure greatly expands the potential benefits associated with the development of later transition phases.

The order of implementation is not hypothesized to be significant in this phase. It is postulated that it is more important to do each practice than the specific order in which the practices are accomplished. Practices within this section include:

1. Identify business issues/goals and develop a strategy - Before subjecting the enterprise to the rigors of a lean transformation it is important to understand why the company wants to become lean. A compelling reason to become lean is necessary to convince the stakeholders of the company (employees, middle management, stockholders, etc.). Whether it is competitive pressures, customer expectations, steady employment, or financial stability, a cohesive consistent message is important to ensure buy in by all stakeholders.

A clear and well-articulated manufacturing policy provides the link required between operations and strategy that establishes a common vision for all employees in the organization. An integrated manufacturing strategy in the overall business strategy helps to develop and strengthen the interface between operations, engineering, finance, purchasing and marketing. These links assist the organization in developing a competitive advantage in product development, manufacturing and customer support.

A manufacturing strategy is important to a lean organization in order to make operating decisions regarding technology, human resources and management in a consistent manner. Once the organization's manufacturing strategy has been developed and integrated with the enterprise's business strategy, an updating process is important to incorporate changes in the environment. In light of a corporation's traditional five year business plan process, the company should review its manufacturing policy annually as part of a short term continuous improvement cycle.

2. Perform benchmarking - Benchmarking is a key measurement process used to help the company understand its competitive environment. Once the company has committed to some level of lean transformation, it can determine how lean the company desires to become in order to be globally competitive. Competitive benchmarking can be used to evaluate the gap between the company and the global leader. This information can then be used to determine the scope and pace of the lean transformation. The establishment of a world-class standard provides the company with a visible target that can be used to keep the entire organization focused on its task. Benchmarking provides the company a means to understand its competitive position within the industry and possibly what needs to be changed. Comparisons between the company's current capabilities and world-class leaders offer insights into improvement possibilities. This process also helps the organization learn about new technologies or management processes from organizations both within and outside of their industry[1].

3. Develop an information technology hardware and software strategy - Companies need to make rapid changes at every phase of getting products to market. Therefore, the formation of links between materials, manufacturing, designers, finance, and service is becoming an operating requirement and not an option. The seamless integration of product data from design to resource planning to plant floor to outside suppliers to purchasing to anyone who needs it is often referred to as the Information Technology (IT) challenge. If a company's information systems are micro-managed at the functional level and are not integrated into an enterprise-wide information systems strategy, the company will end up having islands of information that won't communicate. A more prudent path would be to develop a vision of how all their information systems fit together in order to maximize cross-functional synergy, overall efficiency and speed.

Recent developments in information technology can have profound impact on the lean transformation. Legacy information systems within companies do not allow ready exchange of information between systems. However, more information in the hands of the employees enable them to make better decisions regarding the day to day operations of the company.

Similar to the establishment of the company's manufacturing strategy, the organization can also adopt an information technology hardware and software strategy that will enable the

[1] Lambertus, Todd. "The basis of benchmarking" published by Incentive. Copyright 1995 UMI, Inc. September 1995.

successful implementation of other lean transition phases. The selection of hardware and software must be flexible enough to support future operating requirements.

In the hypothesized model, information technology systems are simplified into the following four areas: data acquisition, information transfer, data management, systems implementation. In the data acquisition area, important questions are: what information is needed, when is it needed, who collects the data and how is it collected? With respect to information transfer, the company should understand who requires the information, what they will use it for, and how they will use it. The answers to these questions will drive the method used for information exchange. Data management refers to data/information standardization, data storage, database management, and data analysis. Once these questions, along with many others not included in this list, are answered the company can then design the system to satisfy its strategy and conduct a make/buy decision analysis in order to initiate the systems implementation phase.

Information technology is an important ingredient to system integration. Therefore current operating requirements are driving the formation of links between materials, manufacturing, designers, finance and other support functions. Benefits in product development due to the integration of common data bases have been experienced in many industries.[2] This has also be demonstrated in the Lean Aircraft Initiative research.[3] [4]

"The companies that seem to be successful tend to integrate their technology investment into some larger organizational change," says Richard Lester, a professor at the Massachusetts Institute of Technology and director of the Industrial Performance Center. Redesigning the IT infrastructure is the same thing as redesigning the organization and organizational charts are all about who needs to talk to whom. Distributed processing is all about which computers need to talk to which ones. As IT executives install new information systems, they are helping recreate the organizational structure.

4. Identify current and needed skills - The lean production paradigm is significantly different from the mass production/job shop hybrid used today and as such requires a greater involvement of the workforce in the daily decision making of the factory operation. Understanding the skill level of the existing workforce is critical to identifying the training opportunities required to bring the workforce up to an appropriate level to sustain lean operations. Identification of both currently required skills and forecasted skill requirements allows a gap analysis between current and required skills. It is beneficial to initiate enterprise-wide training that provides a common knowledge set and language across the organization. The integration of the organization’s strategy into employee training programs provides the opportunity to reinforce the company’s lean objectives.

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[2] DeWitt, John W.; “CAD dreams come true.” Published by Apparel Industry Magazine. Copyright 1994 Shore Communications Inc. April 1994.

[3] Hoult, David P. and C. Lawrence Meador; “Methods of Integrating Design and Cost Information to Achieve Enhanced Manufacturing Cost/Performance Trade-Offs.” Paper presented at the 36th International Society of American Value Engineers Conference. June 1996.

[4] Hoult, David P., C. Lawrence Meador, John Deyst, Jr. and Maresi Berry-Dennis; “Cost Awareness in Design: The Role of Data Commonality.” White Paper -- Lean 95-08. November 1995.

Similarly, the appropriate level of resources required for a lean transition needs to be determined. Under-funding of either money, people, or corporate resolve will most likely lead to "program of the month" status. Therefore, realistic resources need to be committed to match the pace of the lean transformation desired.

5. Fill skills gap with comprehensive corporate wide training - Once the training opportunities are identified with the gap analysis, a corporate wide training program can be designed and implemented to provide the learning foundation for lean understanding.

The acquisition of basic skills (e.g., reading and mathematics) at this phase of the lean transition is crucial in order for the organization to receive maximum benefits from later lean transition phases that include the application of desired skill sets such as Statistical Process Control (SPC). The acquisition of base knowledge during this phase, empowers employee participation and provides the skills necessary to effect change autonomously in their day-to-day operations. Consequently, the hypothesized model places significant value on the acquisition of basic skills.

6. Breakdown stovepipe mentality and establish cross functional linkages - Cross-functional teamwork is critical to lean transformations and requires the removal of barriers between complementary functions. Strong leadership in this area is critical to the establishment of cross-functional linkages. Focus on the products vice the functions is the desired effect which requires the removal of the Not-Invented-Here (NIH) mentality so that a cross-functional organizational structure can support the organization's common goal[5].

The organizational structure that often emerges in lean enterprises is one that focuses its membership on customer satisfaction. Whether internal or external, excellence in quality, schedule and cost must be attained in order to satisfy the customer. The vertical levels of hierarchy, typical of large bureaucratic organizations, if reduced will aid in breaking down the stovepipe mentality. The organization is better served if the functional departments refocus their energies from building barriers to breaking down barriers. As such, all appropriate means should be attempted to break down functional barriers between all functions of the company, especially manufacturing, engineering and purchasing. Matrix organizational structures and integrated product/process teams (IPT) support the processes critical to the enterprise's success[6].

7. Assess technology impacts to manufacturing processes - The effective application of technology can provide significant operating benefits via improved quality and cost performance. However, too often technology is incorrectly applied as the solution to many problems. Therefore, it is critical that the selection and application of technology be aligned with the organization's manufacturing strategy.

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[5] Peters, Tom; Waterman, Robert; "In Search of Excellence." Published by Harper and Row, NY, 1982.

[6] Klein, Janice; Susman, Gerald I.; "Lean Aircraft Initiative Organization & Human Resources Survey Feedback - Integrated Product Teams (IPTs)." White Paper - Lean 95-03. April 7, 1995.

The company should utilize the benchmarking process to measure internal technological advancement with externally available technology. Internal technology development, including both applications and core technology development, should utilize as much commercially available technology as possible. As mentioned earlier, the benchmarking process increases the company's awareness of its competitors and of similar applications in other industries.

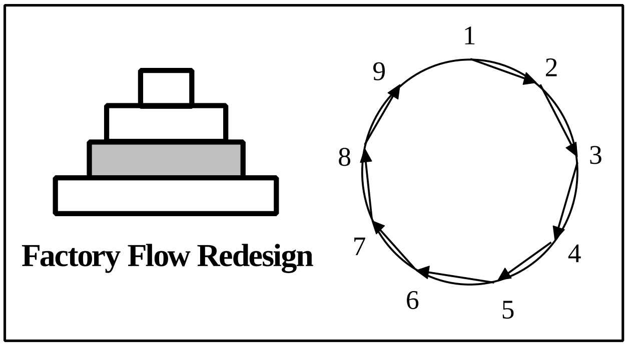
8. Establish linkages with supplier and customer base - To the greatest extent possible, determine and align in-house activities around those that provide competitive advantage and purchase those components that do not. Provide interface mechanisms between the supplier and the shop floor such that the supplier becomes an extension of the in-house manufacturing operation.

Liaison between the supplier and the organization should be strengthened in order to promote learning across both entities. The degree of investment required in this phase will depend greatly on the degree of vertical integration within the organization.

If the supplier base is ignored until the company implements all four lean transition phases, it may be exposed to significant operating risks that are not under direct management control. Once a risk materializes into a major problem, the abatement process may demand significant resources (i.e., labor, material and time). Therefore, as a proxy for direct control, the organization's supplier liaison representative should maintain open communication and direct monitoring of the supplier's capabilities and improvement progress in order to execute effective risk management.

Suppliers must attain the same level of process capability that is required of internal suppliers. Essentially, it is optimal for the supplier to implement similar lean transitions phases which could enable the simultaneous long-term optimization of the entire value chain using systems dynamics concepts.

Phase 2 - Factory Flow Redesign



1. Distribute information
2. Group products into families
3. Standardize processes
4. Design process layout and simulate flow
5. Optimize factory flow and cell linkages
6. Redefine and redeploy work tasks
7. Delegate authority and accountability
8. Construct cells through *Kaizen* events
9. Make product flow visible within the cell

Defense aircraft manufacturers and suppliers can be characterized as low volume developers and manufacturers of highly sophisticated products. The objective in designing any manufacturing process should be to achieve continuous flow or one piece flow depending on the number of flow paths. Either way, these systems can be most easily achieved with the implementation of cellular manufacturing practices. This is a particular challenge in the defense aircraft industry.

After implementing most, if not all, of the steps within the Lean Infrastructure transition phase, the organization is now ready to implement cellular manufacturing techniques on the shop floor. As mentioned earlier, it is critically important that the organization implement the lean transition phases according to the optimal sequence outlined in this model in order to maximize the potential benefits associated with the design of material flow in the factory. If the Lean Infrastructure transition phase is not implemented, the organization's optimization process of factory floor redesign will generate a local maxima efficiency point that is significantly lower than the organization's potential if it had followed the model's specified implementation sequence.

The following sequence of steps are based on a compilation of experiences from members of the MIT Factory Operations focus group. In this case the order of implementation is postulated to be important, therefore, it is depicted with arrows in the picture above. This is a hypothesized sequence and should not be misconstrued as the definitive implementation methodology for lean manufacturing. However, it is important to note that the hypothesized optimal order is not random and does have some logical reasoning to support it.

1. Distribute Information - Distribute as much information to as many employees as possible regarding the manufacturing process, expected demand, quality levels, etc. Distribute all pertinent data to each team member that will participate in the factory floor redesign project in order to fully enable team members to think creatively about the process. Information distribution also means the allocation of computing hardware and software on the shop floor that will be used by team members. Team members must possess sufficient tools and skills to accomplish their objectives.

2. Group Products into Families - Products which have similar part geometries or have similar processing requirements should be grouped together. Using these two methods of segregating parts, one can establish part families. Part families can then be ranked or ordered according to the clustering group technology method[7].

Once the parts are grouped into families, it is possible to reduce the number of process flow paths through the factory operation. This reduction in flow paths may allow an enterprise to achieve a more continuous flow through the factory operation at the same volume.

3. Standardize Processes - After all parts are grouped into part families, manufacturing processes can begin to be modified with the objective of achieving standardized process flows. In this step, operator work methods and/or responsibilities may require redefinition in order to fully optimize the factory flow. To achieve standardization individual part cycle times may increase as a result.

4. Design Process Layout and Simulate Part Flow - Industrial engineering can utilize the standardized process flows and part families to design the manufacturing cell. This cell layout could then be optimized through the application of simulation software. The simulation trials should be analyzed using the following historical and forecasted data: demand levels, demand variability, machine capability, machine availability and space constraints. Cell design and simulation is an iterative process that will require numerous adjustments in order to establish optimal cell design. Software simulation of cells is a relatively inexpensive and easy way of testing a cell design before the cell is physically constructed. The simulation analysis should be conducted under various operating assumptions in order to measure its maximum operating potential. During this process, the systems designer may determine the location of bottlenecks and their impact on part flow in the cell.

5. Optimize Factory Flow and Cell Linkages - Determine which centers flow into each other and design a factory floor layout which optimizes inter-center part flow. Once each cell has been constructed, the next step should be to analyze product flow through the entire manufacturing operation. By examining the linkages between cells, industrial engineering can optimize the entire production system process flow.

6. Redefine and Re-deploy Work Tasks - The new manufacturing cell layout may have been designed under operating assumptions that are different from those of the original system. If so, shop floor tasks should be redefined and redeployed around the reordered products and processes to satisfy the new cell's requirements. Authority and accountability for the cell should also be delegated to the operating area. This may involve the complete rewriting of process/operation sheets.

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[7] There are many part clustering methodologies available in the public domain. For example, Chun Hung Cheng, Ashok Kumar and Jaideep Motwani have published "A comparative examination of selected cellular manufacturing clustering algorithms" in Vol. 15 of the International Journal of Operations & Production Management in 1995.

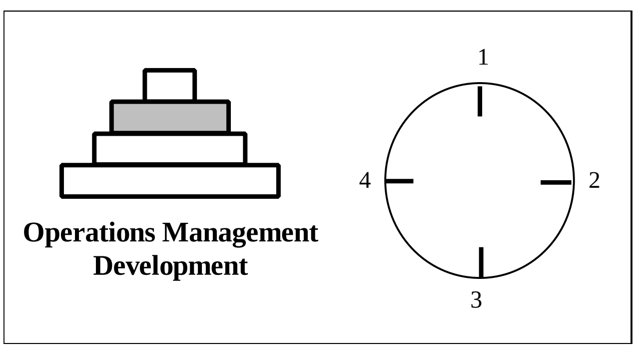
7. Delegate authority and accountability - Empower and hold accountable the employees and management of the manufacturing centers to optimize their productivity and quality.

8. Construct Cells through Kaizen Events - Once the rough redesign of the factory is developed and the new tasks have been defined, utilize cross functional teams and *Kaizen* events (or equivalents) to rapidly re-layout the factory, center by center.

After the engineering groups have developed a proposal, the organization should sponsor a change event, like a *Kaizen* workshop, to solicit ideas from the shop floor and execute the actual layout changes. It is best to actively involve those individuals who have the most direct experience and who will be most affected by the changes. The engineering staff's proposal is based on their prior knowledge base of the entire organization but it may be lacking pertinent operating data specific to certain pieces of equipment or tooling.
Employee support and active participation in these events is important to the success of the factory flow redesign. Shop floor employees should receive adequate training prior to this event and should understand their new operating responsibilities.

9. Make Product Flow Visible within the Cell - In the cell design and design execution, it is important to make product flow visible and obvious within the cell. The objective should be to achieve single piece flow or at least continuous flow within the cell, such that product flow satisfies demand *takt* time. The synchronization of manufacturing within the cell will minimize work-in-process inventory. Visible flow must be designed prior to this step but it is implemented at this point.

Phase 3 - Operations Management Development



1. Cross-train workers and realign incentives
2. Reallocate support resources
3. Implement manufacturing information systems
4. Implement "pull" production systems

After the company has invested in lean infrastructure projects and redesigned its factory flow, our hypothesis is that it can begin to profit from the implementation of additional lean manufacturing practices that are centralized around Operations Management Development. The implementation of Operations Management Development practices recommended in the hypothesized model should enable the company to capitalize on previous transition phases. During this phase, the organization should focus its efforts on rethinking the way work gets done. The tools in this phase support the organization's efforts in optimizing work design and both process and information flow.

After the organization has successfully completed the previous “foundation” transition phases, it can now begin to focus on maximizing the potential of its human assets. In the Lean Infrastructure transition phase, the organization’s leadership began to nurture a work environment that transcended functional silos and clearly communicated common objectives and knowledge to all members and affiliates of the organization. In the Factory Floor Redesign transition phase, the organization’s physical process flow was redesigned. In this phase, the softer elements associated with work flow and information flow will be redesigned.

The following practices are postulated to be important in the management of the operation. The order of implementation is not hypothesized to be significant, however, it is postulated that each practice be implemented. This section is intentionally more detailed as it is here that factory operations managers have the most impact. This additional detail more accurately illustrates the steps involved in managing the lean factory operation.

1. Cross-train Workers and Realignment Incentives - In order to accelerate the organization’s synergistic momentum, it is important to mobilize employees into teams that are focused on product or process management. Employees operating at an individual level reacting to supervisory instructions and predefined tasks must be retrained in order to interact with other individuals on teams focused on the organization’s overarching goals.
During the earlier lean transition phases, employees became indoctrinated into lean manufacturing and have since begun to appreciate real changes in their operating environment with the implementation of cellular manufacturing. Now it is time for shop floor employees to become fully engaged in the execution of the organization’s business strategy. In order to become fully involved, employees in a lean manufacturing environment must become as flexible as the processes they operate. Employee flexibility can be enhanced by providing cross-functional training and mitigating traditional work classification barriers. Similar to the “Breakdown Stovepipe Mentality” step that was focused on functional silos among salaried and management personnel in the Lean Infrastructure phase, shop floor employees must also begin to work together operating under a common goal.

Throughout this relearning process, team-based management practices should be reinforced in order to capitalize on the synergistic benefits of teams. Teams are supportive networks of individuals that collectively optimize the contribution of each individual’s relative specialization. This umbrella charter can be expanded into smaller components that usually stretches beyond what one person could possibly become expert in. Their job descriptions and responsibilities will expand as they begin to excel at multiple tasks in their new operating environment. Cross-functional training also allows each person to become adept at more than one discipline, allowing members to absorb variability in work demands.

The employee gains recognition and respect when working in teams because he/she is given the opportunity to think for themselves. Teams also provide a mechanism that individuals use to identify themselves through their association. The development of a multi-tasking environment reduces system redundancy. This form of waste elimination can be optimized only after employees have received cross-functional training and are executing team-based management practices. Incentives must also be modified in order to support the desired employee behavior. Successful team behavior must be reinforced with recognition that builds pride and with possible economic incentives. Pride and peer pressure are the two major forces that motivate employees operating on teams.

2. Reallocate Support Resources - When workers are given more freedom over their work, they must also be given increased responsibility. In order to empower employees and achieve successful results, the employees must be held accountable for their actions. On the shop floor, this implies that employees directly involved in assembly or manufacturing operations are responsible for the quality of the products they produce. Consequently, employees must begin to monitor the quality of their processes using some methodical procedure such as statistical process control (SPC).

This step transfers the quality control responsibility from the Quality Control (QC) department to the manufacturing department. By building quality into the product instead of inspecting quality into it, the company can eliminate large inefficiencies associated with the QC department. During this transition, QC personnel should provide instruction and training for operators and can also be used as auditors to ensure the standards are maintained.

Reduced staffs have only three alternatives to avoid asset deterioration and its attendant decay in quality and service. They are: 1) improve maintenance worker productivity; 2) reduce the frequency of maintenance exposures; 3) utilize non-maintenance resources.

Total Productive Maintenance (TPM) is the logical goal of departments facing such situations because it is designed around the three remedies to avoid deterioration. Elements of TPM improve maintenance worker productivity, reduce exposures, and bring in operators to supplement maintenance activities. Before TPM, most maintenance departments spent most of their time "firefighting" breakdowns.[8] The value of TPM has also been established with the defense aircraft industry by research in the Lean Aircraft Initiative and methods for implementing have been documented.[9]

TPM is productive asset management. It assesses current performance, identifies problems, sets targets for more effective equipment use and implements a program to bring about the improvement required. TPM involves production and maintenance people working together to achieve its aims. It is autonomous production operator maintenance that attempts to optimize the operator's skill and knowledge of his own equipment to maximize its operating effectiveness. It establishes a schedule of cleanliness and preventive maintenance to extend the equipment's life span and uptime. It requires the involvement of every employee from top managers to the individual team members who participate in the system. TPM's dual goal is zero defects and zero breakdowns.

3. Implement Manufacturing Information Systems - As manufacturing organizations are challenged by an increasingly competitive environment, they must be enabled to mobilize their embedded corporate knowledge. Organizations cannot afford to reinvent the same solutions

[8] Levitt, Joel, "Shape preventive maintenance programs to support TPM", Plant Engineering, October, 1994.

[9] Hamacher, Eugene C.; "A Methodology for Implementing Total Productive Maintenance in the commercial Aircraft Industry." (Thesis for Master of Science degree in the Leaders for Manufacturing Program). Massachusetts Institute of Technology. May 1996.

over and over again and they cannot afford to make the same mistakes over and over again. The learning from one program must be easily and quickly transferred to the next. Information leverage comes from reusable knowledge, reconfigurable for different applications across the entire corporation. Peter Drucker believes that the principle asset in a corporation today is its collective knowledge. The value of that asset is, multiplied by its mobility within the corporation. Most companies today have not thought about themselves as learning organizations - the knowledge base, the changes it undergoes, and how it gets deployed at points that need it while it still has something to offer.

The ability to gather, arrange, and manipulate information with computers has given organizations new tools for managing. Few of today’s information needs are new and conceptually, many of the “new” measurements have been discussed for many years and in many places. What is new is the technical data processing ability. The explosive growth of computer power and expansion of communications technology has done more than simply enable executives to do the same tasks better. They have changed the very concepts of what a business is and what managing means. To manage in the future, executives will need an information system integrated with strategy, rather than individual tools that so far have been used largely to record the past.

Technologies that reduce costs and increase flexibility, such as client/server and open system environments have the highest perceived importance. Also considered top priorities are communications capabilities like enterprise wide electronic mail (E-mail) and voice mail (V-mail), and technologies that promote data/systems integration and improved supplier interfaces, such as bar-coding and electronic data interface (EDI). Programming technologies and those that assist engineering and manufacturing also are considered important.

The key item is the ability to pull together the necessary information from wherever the source to the point of use so that informed decisions can be made by the people most involved in the operation. Having the information available to someone who cannot affect the operation is not good enough. The information system needs to be robust enough to be accessible by those people who can directly act on the information. Information systems which are specifically designed for a particular task and use, sometimes called legacy information systems, tend not to be as useful across functions. This incompatibility of data structure makes it difficult to access information needed by many different users. Therefore, effective use of information requires an information strategy expressed in the Lean Infrastructure portion of the model.

4. Implement Pull Type Production Systems - Material Requirements Planning (MRP) systems provide easy access to and visibility of information on the stocks and flows of material within the supply chain and the physical capacities of selected operations. Such a window of simplicity can only be achieved, however, if part numbers, bills of material, stocking procedures and engineering change notice updates are meticulously defined and data integrity scrupulously maintained. These systems assume infinite capacity and do not account for normal plant production perturbations that occur. A further enhancement of MRP systems is the simulation of flows limited by finite scheduling capacity specifications. These systems however are push systems. This does not mean that they should be scrapped, however, they should be used more for large system planning while some other pull system is devised for shop production. You can consider MRP the macro scheduler whereas the micro scheduler should be pull based.

As we have seen, lean manufacturing includes the formation of manufacturing cells, flexible teams and autonomous quality control. The result is the elimination of job specialties and hierarchical classifications and a reduced need for inspections by quality controllers. And in addition to these changes, inventory has also been significantly reduced in lean manufacturing organizations. Some organizations that have undergone lean transitions have replaced their large inventory supplies with kits that only contain the parts necessary for a cell to complete a particular task[10]. Since the kit is often bubble-wrapped by a transparent cover, it is immediately obvious if a part is missing. Once the cell starts using a kit, another is automatically called for to replace it, 'pulling' stock through the system in a Japanese *Kanban* technique[11]. This sharply reduces the volume of parts held in stores, and completion rates rise because there are fewer shortages. A control mechanism can be set up at the end of each manufacturing cell to direct high-value parts. These "regulators" may consist of dunnage which circulate among the cells and each contains only enough materials for one aircraft; when the box arrives empty at the supplier cell, it represents a "fill me and pass me on" signal[12].

Synchronous manufacturing systems are “pull-based” production systems which draw parts forward on the line as they are required rather than “pushing” them from behind and causing bottlenecks and waste. The *Kanban* can be footprints marked on the floor at work stations that contain only one of the production items to be passed on to the next station or taken up from the previous station. It can also involve cards to be attached to and passed on with the item, but should otherwise eliminate much paperwork[13].

Similarly, JIT manufacturing implies a pull system of production where the demand at subsequent work centers drives the production at a given work center. Production batch size is small, resulting in low WIP and raw material inventory. In a JIT system, demand imposed by work centers downstream triggers production at any work center. If a work center is busy, demand is stored in a queue called the demand list until it may be satisfied. JIT systems are disciplined systems that include a constant devotion to problem solving and continuous improvement, the sharing of production planning and scheduling information, and good housekeeping.

In these types of systems, input storage areas for each work center are designed to minimize the amount of inventory that could be stored at any station. One benefit of the system has been an improvement in material handling. Before using the system, it was material handlers who would know where to take parts in the shop and, therefore, they would

[10] British Aerospace’s Samlesbury facility is an example.

[11] Kanban, meaning “ticket” or “signal” in Japanese, is a management tool in general use in Japan and developed by Toyota from US company Sears' tickets for limiting public access to its store.

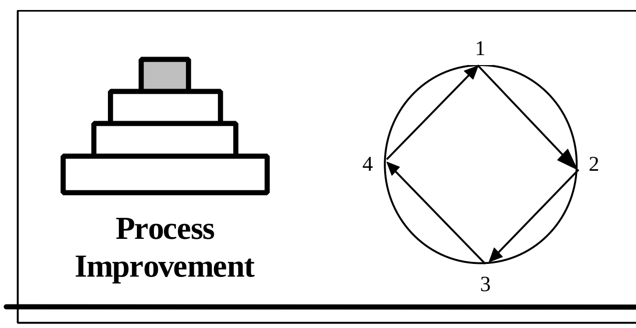
[12] Gray, Bernard; Financial Times, December 18, 1995: “Special Report on British Aerospace: Managers must have the courage to trust their people.” Copyright 1995 The Financial Times Limited.

[13] Pohling-Brown, Pamela; International Defense Review, April 1, 1995: “No time for banners: UK companies develop lean production with Japanese advice.” Copyright 1995 Jane's Information Group Limited.

be responsible for most of the material handling. The upfront planning has eliminated this and now each operator transfers material from one station to the next. In job shop environments, the operator uses computer generated process routings to transfer products through the plant[14].

Michael Cusumano, Professor of Management at MIT Sloan School of Management, notes that sometimes it may become impractical to let the manual exchange of *kanban* cards pull new orders of components into the production system and relay all production information. There may be better methods available (such as the use of bar-code readers and other electronic forms of moving information) for plants with very high levels of variety -- which covers many factories in the defense industry.[15]

Phase 4 - Process Improvement



1. Improve process and operations predictability
2. Improve process quality
3. Increase process flexibility
4. Increase process speed

[14] Mukherjee, Amit; Huber, Ernest; American Machinist, July, 1994: “Just-in-time control works at tool and die shop.” Copyright 1994 Information Access Company, a Thomson Corporation Company, Copyright 1994 Penton Publishing Inc.

[15] Cusumano, Michael A.; Sloan Management Review, June 22, 1994: “The limits of lean.” Copyright 1994 Sloan Management Review Association.

The last major lean transition phase in the hypothesized LAI Factory Operations Model focuses on optimizing or improving individual processes within the manufacturing system. Some companies may implement this phase before some of the other phases due to lower required capital investments but the potential benefits that they will receive may be limited to the successful implementation of previous lean transition phases. An analogy in this case would be to consider the previous transition phases as part of a process that optimizes the entire system and this phase as a process that generates local maximums but does not necessarily produce a system maximum.

The following sequence of steps is postulated to be important in continuous improvement. In this case, the order of implementation is hypothesized to be important.

1. Improve Process and Operations Predictability - The first step within this phase is to stabilize the process. Independent of output quality, it is important to understand the system and to be able to predict its performance. Even if the process produces 30 percent defective parts, the focus of process improvement should be on reducing its operating variance before focusing on improving its capability, flexibility or speed. The application of common work standards and variability reduction tools are often used to improve process stability.

Many companies focus on new technologies in their efforts to improve their processes. When yields are low or process problems cause poor throughput and delivery performance, the first response is often to consider a major process upgrade, either through investment, new technology or both. Turning too quickly to investment or new technology can cause the company to neglect inexpensive, yet possibly significant, improvement leverage that can come from better process discipline[16].

Process discipline means that process inputs must be controlled. Not only does this include physical inputs to the process (i.e., ensuring that raw materials are within specifications), but it also includes process documentation, training of employees, process audits, calibration procedures and gages, maintenance management, change control, and investment in a comprehensive production report. The focus of this step is to use formal systems to improve the consistency of inputs to the process, thereby reducing process variability. Without consistent inputs, there is no hope of achieving consistent outputs[17].

The inconsistencies arising from the lack of discipline will make many processes appear to be out of control, or not capable. In a high-variability environment, it is difficult to identify the cause-and-effect of problems. It is even more difficult to test a hypothesis and get a result with high confidence, and to be sure the proposed corrective action really works. Identification, testing and fixing are all much easier with the consistency that results from good process discipline[18].

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[16] Treville, Suzanne de; Edelson, Norman M.;); Industrial Engineering Sept., 1994: "Process discipline: rethinking technology investment." Copyright 1994 Institute of Industrial Engineers Inc. (IIE)

[17] Ibid.

[18] Ibid.

2. Improve Process Quality - After the process has become stable and predictable, the organization can begin to focus its efforts on improving the quality of its output. The objective should be to get the process under statistical control by use of experimentation, statistical process control (SPC) and other methods in order to identify and correct assignable cause-type problems. Improved process capability (measured by C_{pk}) is the result of the application of statistical process control methods, operator certification, and error-proofing systems like *poka-yoke*.

Japanese *poka-yoke* systems ensure that certain, previously identified defects cannot occur. For example, assume that a defect occurs each time material is fed into a process upside down. A *poka-yoke* device would detect the upside down condition and prevent the defect by stopping the machine. *Poka-yoke* devices provide 100% inspection for abnormalities at a fraction of the cost of traditional inspection methods, while eliminating defects at their source before they have a chance to occur.

3. Increase Process Flexibility - Once the process is capable, then the company can begin to focus on expanding or increasing the flexibility of its bottleneck operations. This includes the application of flexible tooling, computer numerical control (CNC) machine tools and set-up time reduction programs.

Obviously, a high level of process discipline is critical to determining where the firm should invest its capital. Poor process discipline leads to low capital efficiency. The achievement of process discipline in the first step leads to a higher probability of success with new technologies or investments. In both this step and in the following step, the organization may begin to consider capital investment or technological breakthrough as a mechanism to improve their process capability.

4. Increase Process Speed - The very last step within this lean transition phase is to increase process speed[19]. This is the last step proposed by the hypothesized model because in most organizations the successful achievement of the previous three steps provides significantly greater benefits than could be provided by increasing equipment speed. Methods of increasing process speed include the application of different processing equipment or conducting studies to improve the man-machine interface.

Lean Implementation Model Description

Now that the individual implementation phases have been defined, Figure 1 (shown earlier) presents a framework which depicts the interrelationships of the phases. To recap, the framework is presented as a foundational structure with the following hypothesized optimal sequence:

[19] Some incremental process throughput benefits will also accrue to the system by improving process flexibility in the previous step.

1. Lean Infrastructure
2. Factory Flow Redesign
3. Operations Management Development
4. Process Improvement

Further, it depicts that the more phases accomplished, the greater the benefits received from the lean transition. Lastly, the model illustrates that each time a phase is implemented the company incurs costs in the form of money, time, and “culture confusion”. Culture confusion can be thought of as the aggregate confusion that occurs in all functions when a change is implemented. Therefore, each time a phase is revisited it incurs these costs over again!

The optimal sequence depicted is very similar to the process used by well known “green field” plant sites where every aspect of the operations organization is questioned and realigned to optimize the entire operation. The Toyota assembly plant in Georgetown, Kentucky is an excellent example of a “green field” lean implementation.

However, most aerospace companies and, in fact, most companies utilize the inverse sequence. They start by improving their manufacturing processes. This is followed by changes in how the factory is managed, which is followed by a rearrangement of the factory. Finally, the company deals with the underlying issues of how to become lean and what must be changed at a more basic phase to fully benefit from the lean transition. The reason for this is that for most aerospace companies the lean enterprise paradigm was not developed and companies experimented with the easiest lean phases first and became more deeply involved over time. This can be thought of as the “Brown field” lean transition process. There is nothing fundamentally wrong with this approach other than the fact that each time a company enters a new phase, costs are incurred in the form of money, time and culture shock. Ultimately the company should follow the optimal sequence in order to receive maximum benefits; however, if it followed the inverse sequence, it would increase the costs of the lean transition, but the lean transition itself would still occur.

It is important to understand that the steps listed earlier within each phase are not one time actions and in fact the steps should be iterated through each phase continuously. Similarly, the lean enterprise paradigm will continuously change; therefore, the lean transition process must be iterated as well. Consequently, Figure 2 provides an additional view of our model which accounts for the short and long term continuous improvement cycles and the relevance of benchmarking within the transition process.

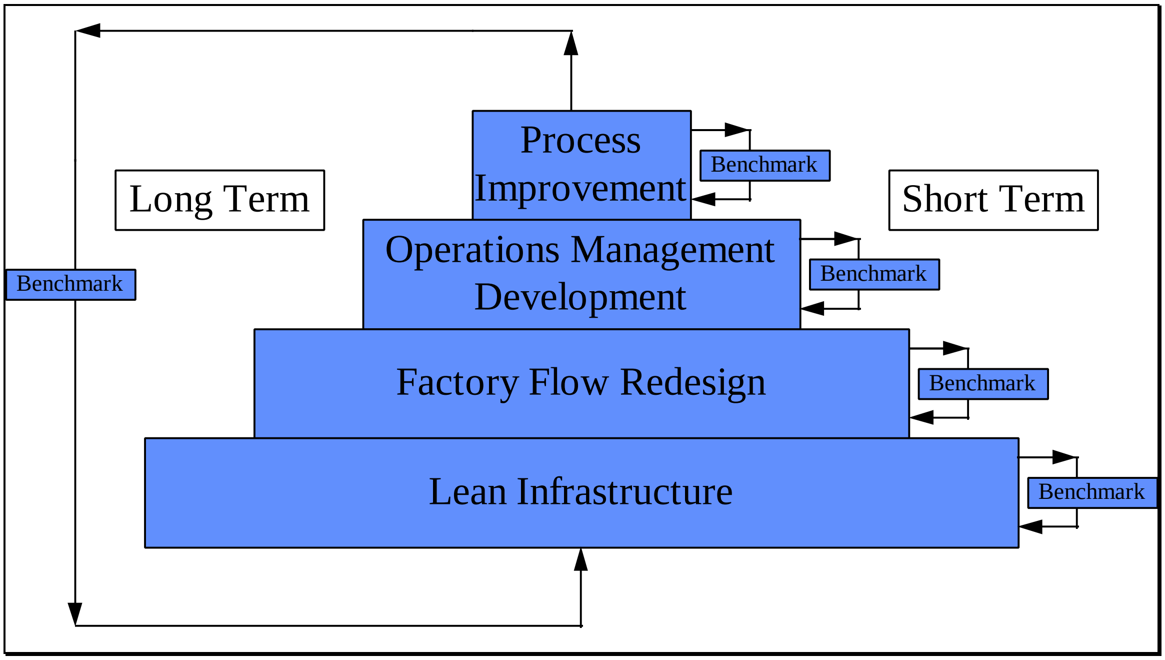


Figure 2: Continuous Improvement Cycles

The final view of the hypothesized model depicted in Figure 3 accounts for the fact that each company when transitioning to lean has its own unique circumstances and may benefit from each phase differently. Additionally, this view of the model depicts the foundational nature of the phases more accurately than Figure 1.

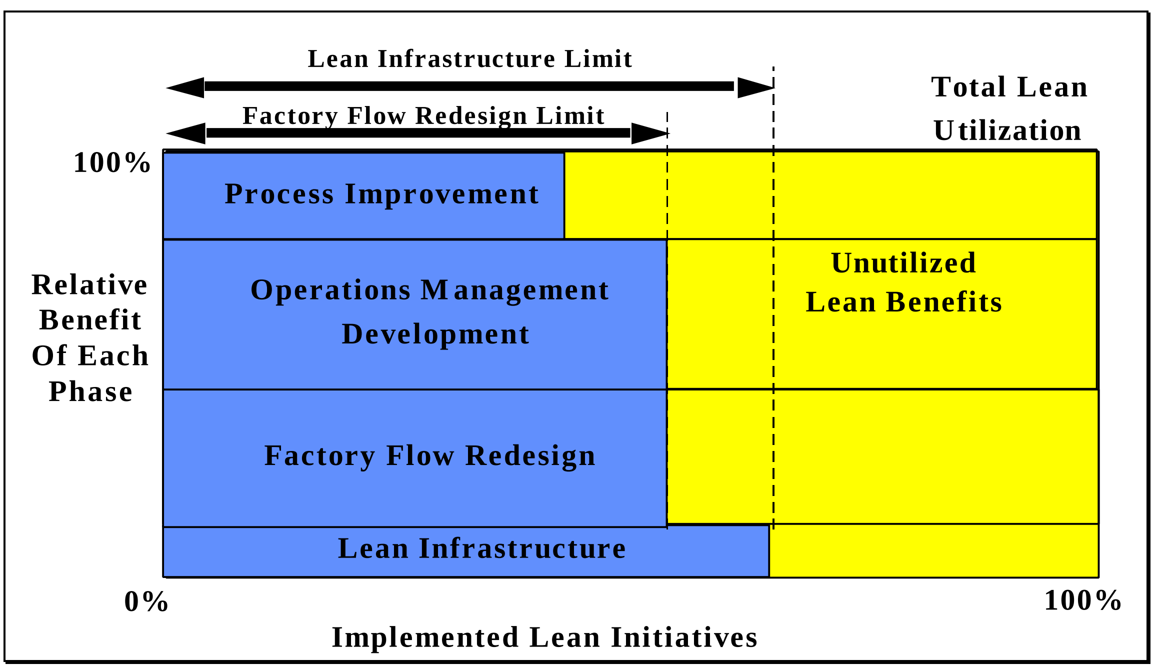


Figure 3: Foundational Effects and Company Circumstances

Figure 3 illustrates the relationship between transition phases. The hypothesis is that each phase is dependent on the phase below it. In this example, approximately 70 percent of the potential lean infrastructure initiatives were implemented. This implies that the degree of implementation of the later transition phases (e.g., Factory Flow Redesign, Operations Management Development and Process Improvement) are limited to 70 percent. The hypothesis implies that the potential benefits from the implementation of initiatives in these later phases are also limited to 70 percent. The degree of implementation of any lean transition phase restricts the potential benefits that may be achieved in any later phase by the degree of implementation of the preceding phases.

Similarly, if the Factory Flow Redesign initiatives are only applied to 60 percent of the factory then the Operations Management phase, which includes the implementation of a pull type production flow, will be restrained by the remaining 40 percent of the factory which is organized and managed in the old manner. Consequently, if a company wants to maximize its utilization of its lean transition then it must perform as many of the lean initiatives in each phase as possible. Furthermore, it reinforces the optimal sequence in Figure 1 since it makes sense to adopt the lean infrastructure initiatives first so as not to limit the potential of the factory flow redesign, operations management development, and process improvement phases. This should not be interpreted that all the lean infrastructure initiatives should be implemented before the first factory flow redesign initiative is started. Rather a parallel approach should be used where all the phases are being implemented simultaneously with the lower phases slightly ahead of the phases above them.

This view enables the model to provide for the unique circumstances of each company. The relative benefit of the phase is represented by the height of each of the phases. The larger the height represents an increase in the benefit the company will receive from that phase. For instance in this particular company the operations management development and factory flow redesign phases will provide significantly more benefits than the process improvement and lean infrastructure phases. However this does not mean that the latter two phases should be ignored due to the aforementioned foundational affect.

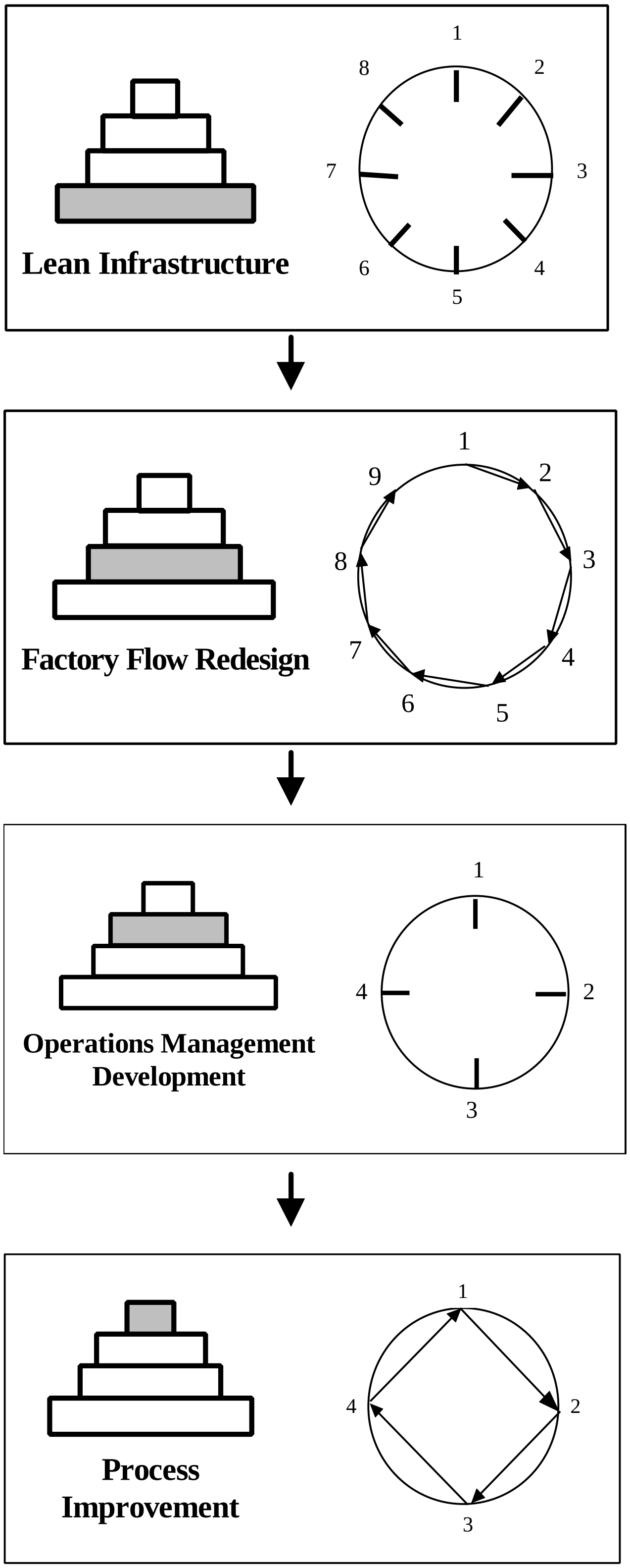
Case Studies

Introduction

Case studies were used to test the hypothesized Lean Implementation Model. There were three types of case studies used in this test: case studies done specifically to test the hypothesized model, case studies that had been accomplished prior to the creation of the hypothesized model, and reviews of other theses that addressed specific aspects of lean transitions. The case studies specifically done to test the hypothesized model were most thorough in testing all aspects of the model but were based on only three case studies. Case studies that had been accomplished before the creation of the hypothesized model were valuable but may not have gathered information to compare all layers of the hypothesized model. The reviews of previous theses revealed good information in very focused areas, but it was harder to understand broader implementation issues.

The case studies done specifically to test the hypothesized model are in Appendixes A, B and C. The case studies accomplished previously but compared to the hypothesized model are in Appendixes D, E, F, and G. Finally, those comparisons to specific lean transitions are found in Appendixes H, I, J, K, and L.

All the case studies were compared to the hypothesized lean implementation model to determine the steps that were utilized in their lean transitions. These steps were captured using the hypothesized model as a framework. The actual case studies have been published in separate documents which are referenced in each appendix. The analysis of the case studies relative to the hypothesized Lean Implementation Model will be accomplished in this section. The specific characteristics of the case studies that were attributed to the steps in the hypothesized Lean Implementation Model are provided in the appendixes, one for each case study. In each of these case studies, we used the graphical description of the hypothesized Lean Implementation Model to show the implementation as we understood it. This graphical description is presented in Figure 4 for your reference.



Lean Infrastructure

1. Identify business issues/goals and develop a strategy
2. Perform benchmarking
3. Develop an information technology hardware and software strategy
4. Identify current and needed skills
5. Fill skill gaps with corporate wide training
6. Breakdown stovepipe mentality
7. Assess technology impacts
8. Establish linkages with supplier and customer base

Factory Flow Redesign

1. Distribute information
2. Group products into families
3. Standardize processes
4. Design process layout and simulate flow
5. Optimize factory flow and cell linkages
6. Redefine and redeploy work tasks
7. Delegate authority and accountability
8. Construct cells through *Kaizen* events
9. Make product flow visible within the cell

Operations Management Development

1. Cross-train workers and realign incentives
2. Reallocate support resources
3. Implement manufacturing information systems
4. Implement “pull” production systems

Process Improvement

1. Improve process and operations predictability
2. Improve process quality
3. Increase process flexibility
4. Increase process speed

Figure 4: Hypothesized Lean Implementation Model Steps and Sequence

Case Study Number One

The analysis of this case study relative to the hypothesized Lean Implementation Model is in Appendix A. Based on the information obtained in conducting this case study the researcher attributed the sequence to the lean implementation in this case as shown in Figure 5. Each box or level in the diagram represents a stage of lean implementation.

In the first stage of lean implementation the company sought long term infrastructure changes based on a set of corporate goals and an implementation strategy. This was reflected in strategic decisions about core competencies to be pursued. These decisions impacted the skill needs of the company. Although benchmarking was performed, it was focused on the area which was eventually outsourced. One of the strengths noted was a very determined effort to develop an information system that used a common, open system architecture to replace many legacy systems. This open architecture system improved information availability to all who needed it. Another tenet in this stage was the transition from a functional organization to a programmatic team based operation structure. In this stage, Integrated Product Teams (IPTs) were used on new programs while older programs retained their functional organizational structure. Also in this newer program, technology solutions like common design tools among major suppliers were mandated.

In the second stage of lean implementation the primary emphasis was on factory flow redesign. Many of the factory changes were incorporated in the company's new program. The production of subassemblies for the assembly line was moved to be adjacent to the assembly line. With this coupling, subassembly starts were linked to the assembly line needs and delivered to the assembly line when needed rather than being delivered to storage. Many process steps were standardized and deployed for better product flexibility.

The third stage of the lean implementation reflects the learning that occurred with the two previous stages. For instance, virtually all items in the lean infrastructure phase were revisited during this stage. It is important to recognize that the missing elements from the hypothesized model from stage one were addressed in this stage. In particular, to support the new program, a company wide training program was initiated for assembly line workers. Expanding the IPT concept to suppliers was a natural progression in this phase. Simultaneously, Operations Management Development items were pursued to cross-train workers and to reallocate support resources (including supplier resources).

Finally, the last stage reflects the process improvements effected to improve the quality of the product. These efforts were primarily focused on reducing the process variability and improving the quality of close tolerance holes in the product.

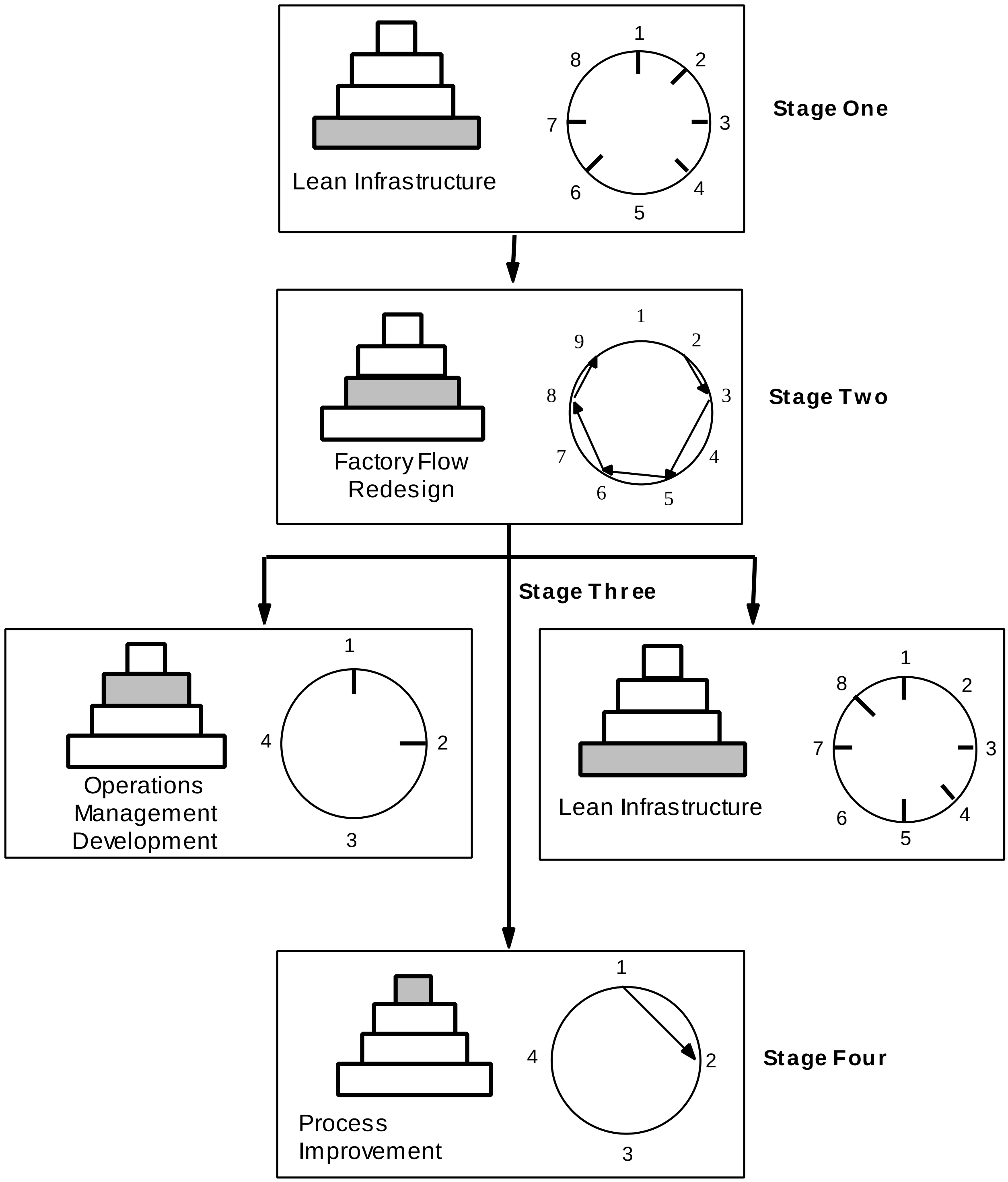


Figure 5: Case Study Number One Implementation Sequence

Case Study Number Two

The following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Figure 6 shows the process or sequence followed. Each box or level in the diagram represents a stage of lean implementation.

The first stage was characterized as lean infrastructure building. This was started before the modernization program with a Total Quality Management program. This program had limited success but did focus on employee training and addressed the cultural changes necessary in the models lean infrastructure phase. Later in this stage benchmarking activities occurred which became the impetus to continue the lean transition and to focus their next efforts onto a factory modernization program.

In the second stage of the transition, the company addressed factory flow redesign and operation management development ideas simultaneously. At the time of our case study this stage had just been completed. We found that the factory flow redesign state was characterized by a rapid change from functional manufacturing processing areas to manufacturing cells. Unique methods were used to determine the product grouping necessary to establish efficient cells. They executed the changes with teams of engineers and managers using shop floor operators to fine tune the layouts within the cells. Concurrently they started employee training and the reallocation of support resources.

In the final stage of this transition we witnessed a renewed effort to understand their process capabilities and to improve their process quality. We also saw technology employed to increase process speed.

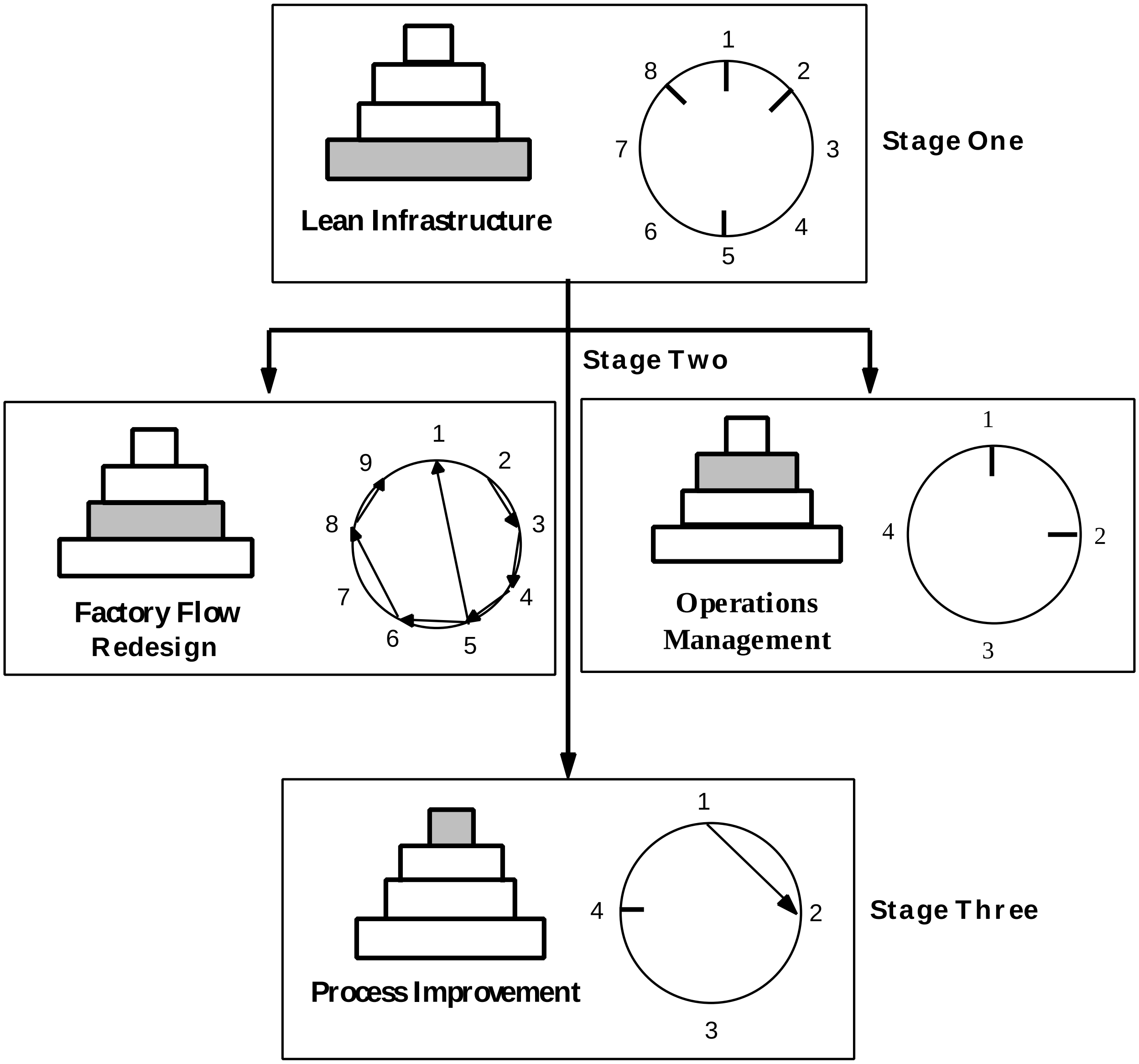


Figure 6: Case Study Number Two Implementation Sequence

Case Study Number Three

The following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Figure 7 shows the process or sequence followed. Each box or level in the diagram represents a stage of lean implementation.

In the first stage of this lean transition, the whole company started lean infrastructure changes with emphasis on information technology, acquiring the needed skills, employee training and linkages with their suppliers. This effort focused on Self-Directed Work Teams (SDWTs) but was not universally successful.

The second stage's focus on operations management followed closely behind the first stage. Associated with SDWTs, the company initiated a pay-for-knowledge program as it transitioned away from functional organizations. These efforts ran into problems however, which forced a refocus on their transition.

The third stage of their lean transition focused on applying lessons learned from their previous efforts and reallocating employee responsibilities. Benchmarking how others had realigned their workforce led to the application of all but one of the elements of the lean infrastructure phase of the hypothesized lean implementation model. In this round of lean infrastructure development, the company concentrated more on the humanistic side of the implementation.

After reemphasizing the lean infrastructure efforts, the forth stage capitalized on this foundation to simultaneously focus on operations management and factory flow changes. In particular, a new round of worker training and support reallocation through the implementation of IPTs occurred as the teams focused on streamlining the flow of product and establishing assembly cells.

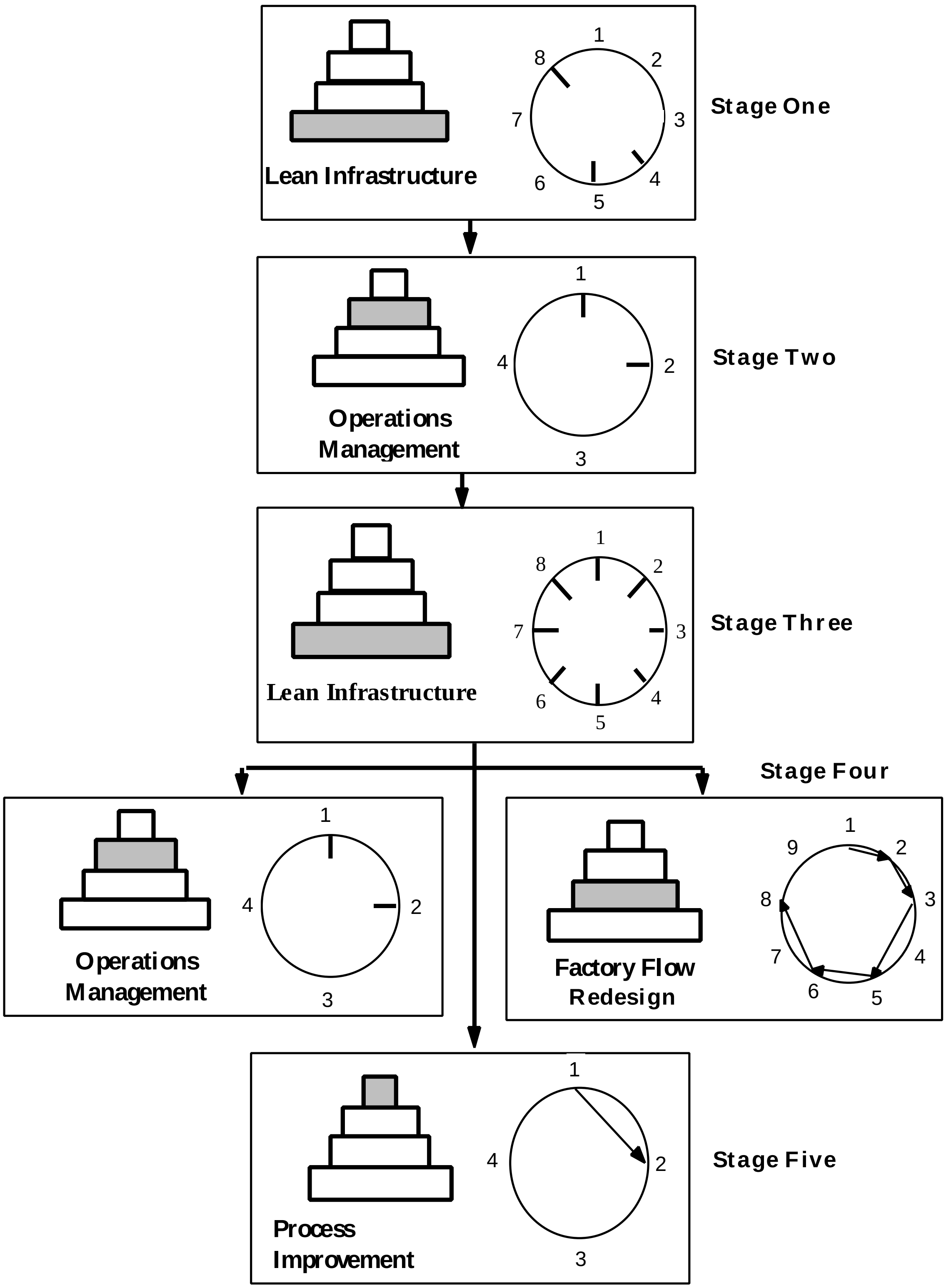


Figure 7: Case Study Number Three Implementation Sequence

Case Study Number Four

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Figure 8 shows the process or sequence followed. In this case the performance improvements were characterized by a gradual process of incremental improvements over a five year period. Each box or level in the diagram represents a roughly chronological stage of lean implementation.

The fourth case study exemplifies the situation the aircraft industry faces. Over a six year period, this company saw falling orders, growing product mix in a given factory operation and the need to reduce production costs. The differences before and after this lean transition were the implementation of work teams, quality improvement teams and several flow process layout changes. This case focuses on continuous improvement which was largely driven by employee empowerment and was set up in the first stage of this transition. Prior to this lean transition the factory operation had control of only 33 percent of the operation steps that processed the products going through the factory operation (in other words, 67 percent of the operations necessary to make the product were completed outside of the manufacturing product manager's area of responsibility-see details in Appendix D).

Improvements during stage two of the transition was executed largely through management actions. By 1990, improvements had reached a plateau and it took a fundamental change to continue improvement. This change marked stage two of the transition which was the restructuring the process layout into product cells and simultaneously giving the workers in the cells responsibility for the production of the product. After the perturbations due to the change of the layout and the culture change of workers in control of the process, improvements continued. During stage two of the transition, the organizational control was increased to 50 percent of process steps.

In stage three of the transition, continuous improvements from work teams contributed to flow time reductions which led to additional layout changes. After the transition the factory operation controlled 91 percent of the operation steps required to produce their product. Stage three was characterized by a near pull flow system using *kanbans*. The product is not introduced into the factory unless all components are available. Only two hours of work are taken by employees at one time with a first in, first out working order. Flags are used to indicate need for work in the cells. Kanban boards with preset management limits indicate the WIP accumulation at bottlenecks.

After stage three the factory operation was completely visible. By walking the floor a novice can see the status of manufacturing with problem areas highlighted for everyone to see. The workers load the factory operation. Based on an MRP II window of opportunity, the workers at the first operation determine what to introduce into the factory using process knowledge and daily takt meetings on cell status.

Finally, stage four is marked with improvements in quality and further flow time reductions. Quality improvements have materialized not by focusing on quality but by continually improving flow time and reducing WIP.

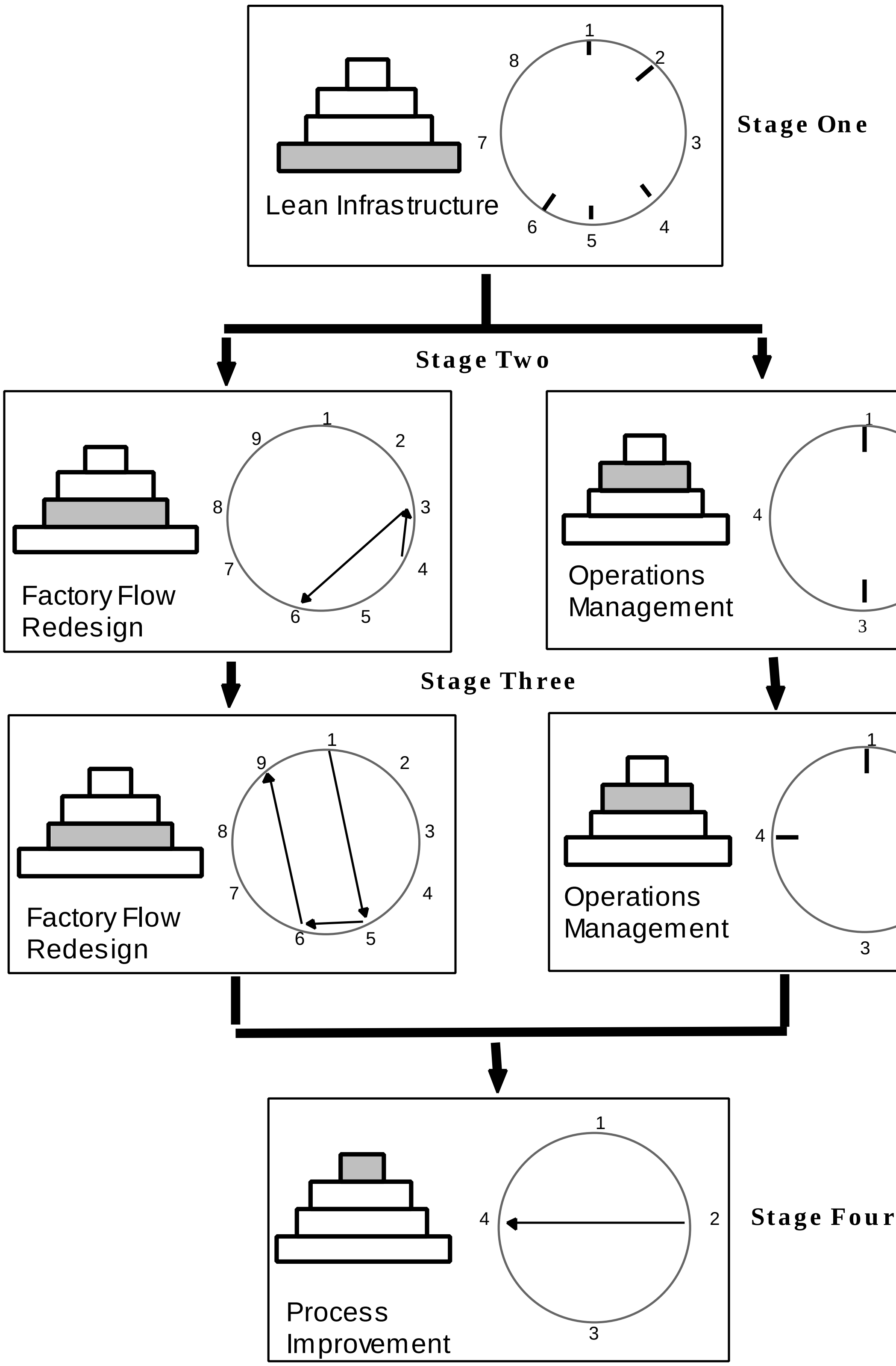


Figure 8: Case Study Number Four Implementation Sequence

Case Study Number Five

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Figure 9 shows the process or sequence followed. Each box or level in the diagram represents a roughly chronological stage of lean implementation.

In stage one of this implementation, the company supported a small team of production managers and engineers who defined a program for the company to transition to leaner operations. In this process this team overcame significant cultural resistance to develop a plan to redefine how products were produced in their factory. This plan was focused on the highest sources of waste with which they could effect change.

In concurrent activities of factory flow redesign and operations management development which marked stage two, the team identified an area to implement their ideas and created the first focused factory. Though some innovative use of information and part handling systems, the team reorganized an area to match authority with responsibility about a common product family. After the establishment of a focused factory, stage three was marked with process improvements through experience with the new system and employee inputs. Finally, stage four was marked by the establishment of a raw material pull system.

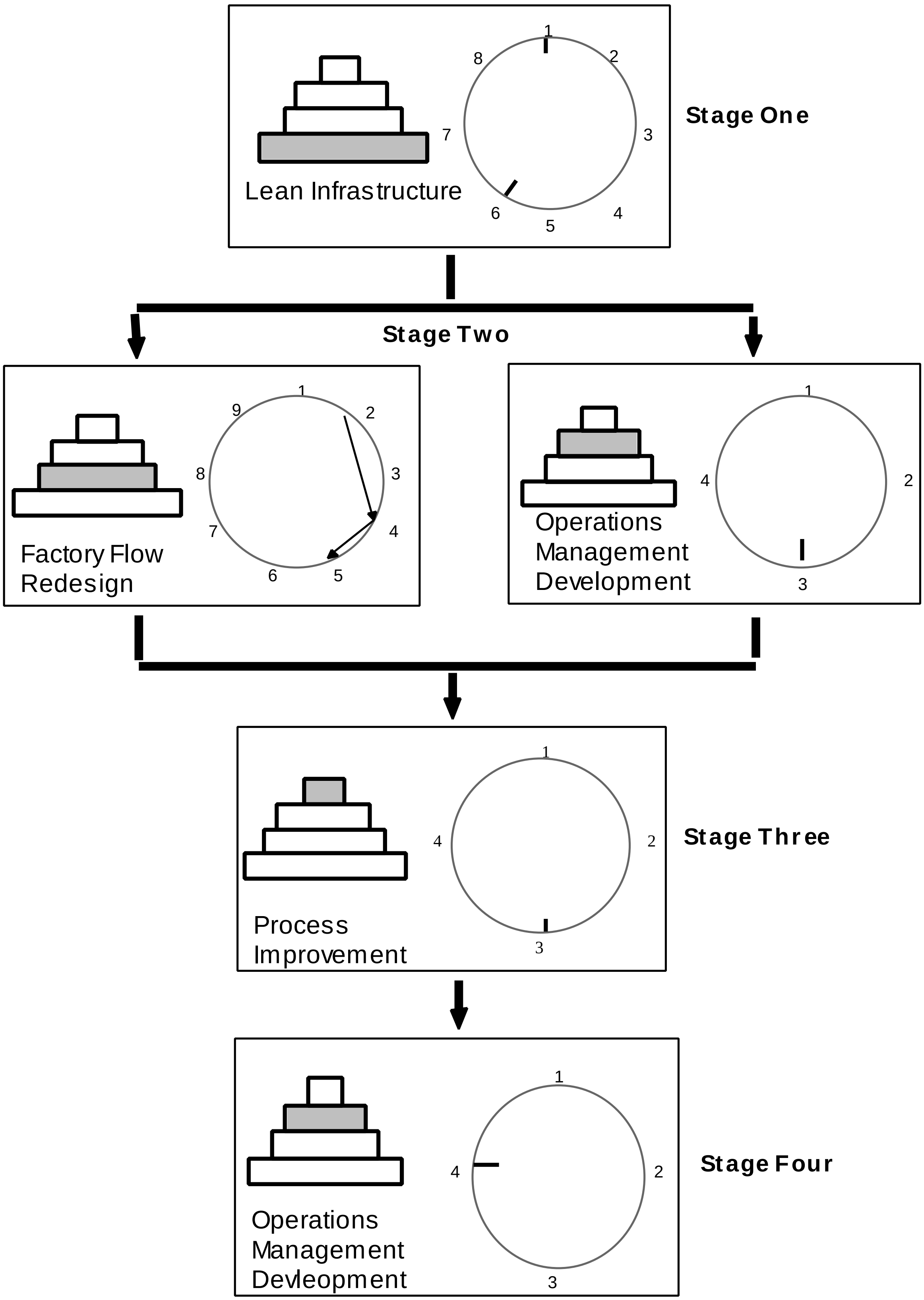


Figure 9: Case Study Number Five Implementation Sequence

Case Study Number Six

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Figure 10 shows the process or sequence followed. Each box or level in the diagram represents a roughly chronological stage of lean implementation.

In stage one, the company developed a strategy which was passed on to all divisions. In this case, the General Machining area also developed a strategy for its lean transition which involved the members of the area. The major focus in this stage was on communication of the strategy and the implementation of employee empowerment.

In stage two the factory flow redesign and operations management development phases occurred concurrently. The major emphasis was management's definition of product grouping followed by rapid redeployment of equipment to satisfy a new cellular layout initially designed by manufacturing engineers and later refined with operator *kaizen* events. As part of the layout design, workers were cross trained for multiple operations, and cell management and operators were challenged to implement single piece flow to achieve pull production.

In stage three, the process improvement phase followed the major activity associated with the redesigned layout and concentrates on further refinements to the cell after the initial layout change. Process improvements have come from standardization, multiple *kaizen* events and setup time reductions.

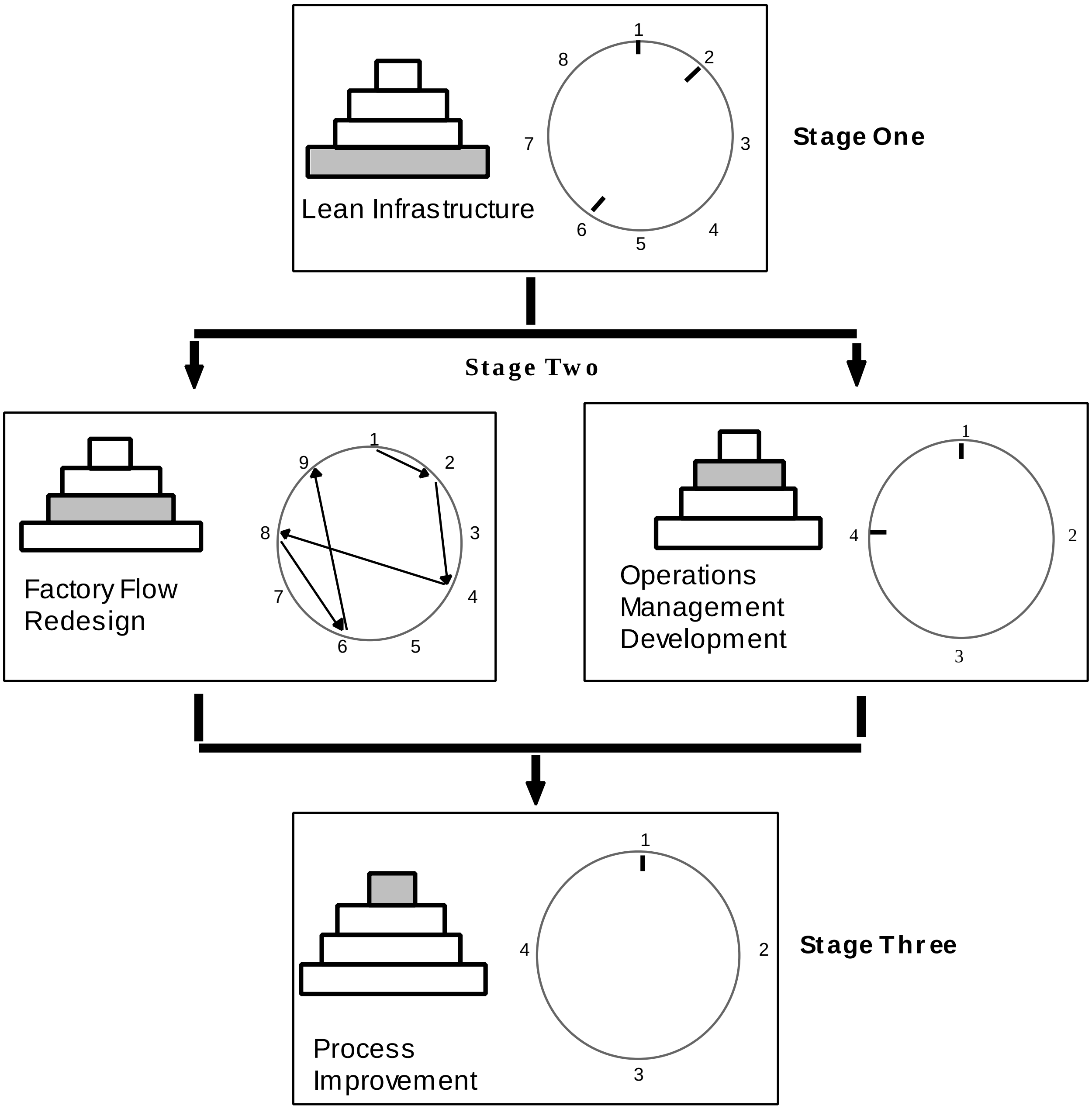


Figure 10: Case Study Number Six Implementation Sequence

Case Study Number Seven

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Figure 11 shows the process or sequence followed. In this case study, only one stage was observed concerning the process improvement phase of the model. This company used key characteristics to focus its efforts. At each key characteristic, it defined the process capability needed to achieve that characteristic and then proceeded to improve the process until the key characteristic was obtained. In this process, the company followed, in sequence, all the steps postulated by the hypothesized model for this phase.

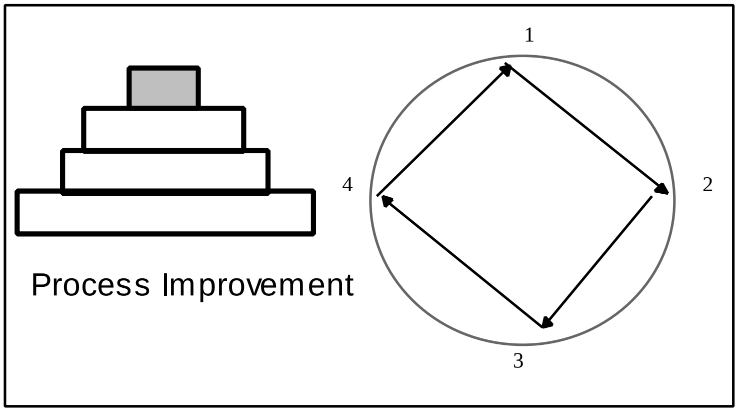


Figure 11: Case Study Number Seven Implementation Sequence

Case Study Number Eight

Following is a description of the implementation sequence proposed in this case study and it's comparison to the hypothesized Lean Implementation Model. Appendix H Figure 1 shows the process or sequence proposed. Each box in the diagram represents a roughly chronological stage of lean implementation. In this case study only one implementation phase was observed.

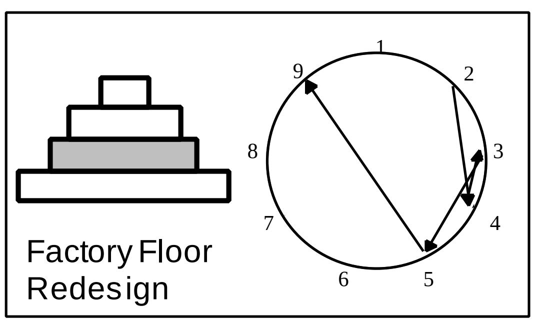


Figure 12: Case Study Number Eight Implementation Sequence

Case Study Number Nine

Following is a description of the implementation sequence proposed in this case study and it's comparison to the hypothesized Lean Implementation Model. Figure 13 shows the process or sequence proposed. Each box in the diagram represents a roughly chronological stage of lean implementation. In this case study only two implementation phases were observed. The limited application of this case study to the model is most likely due to the focus of the thesis. The thesis concentrated on improving the system using a particular process as the focus of the study.

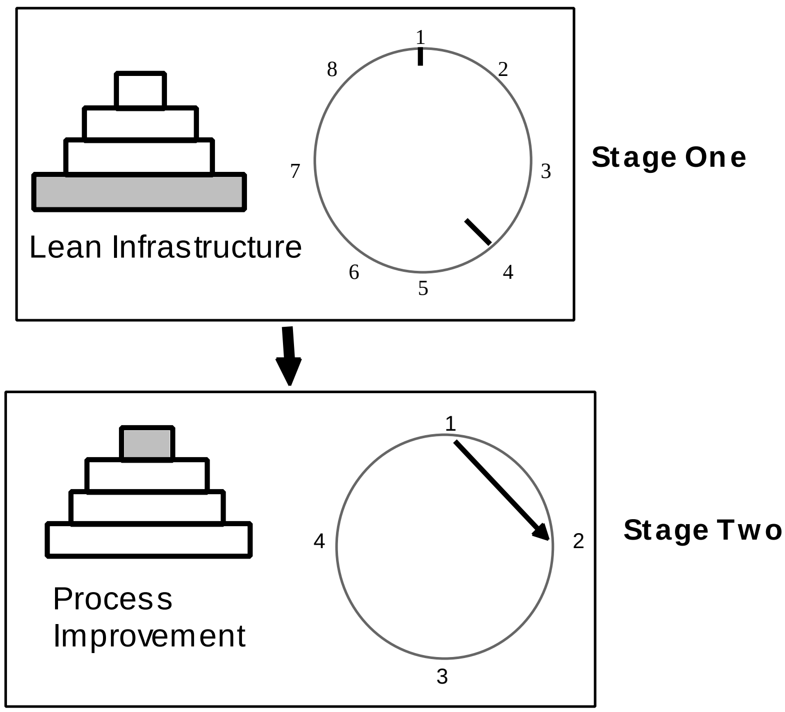


Figure 13: Case Study Number Nine Implementation Sequence

Case Study Number Ten

The case study presented in this thesis only applied to phase 1 and phase 4 of the Hypothesized Lean Implementation Model. We found that phase 2 of the model could not be applied in continuous process cases. Therefore, in companies using continuous processes Phases 1, 3, and 4 are the only phases that make sense. Figure 14 illustrates the process followed by this company compared to the Hypothesized Lean Implementation Model. This case study is similar to the previous case study and the same phases were used in each case study.

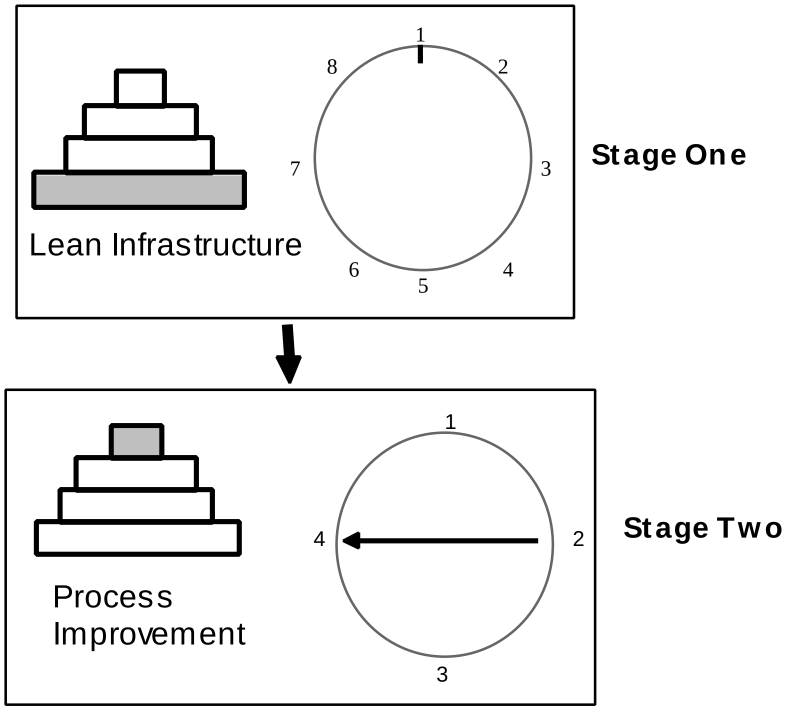


Figure 14: Case Study Number Ten Implementation Sequence

Case Study Number Eleven

The case study presented in this thesis only addresses phase one and phase two. This case study was mainly focused in analyzing how to optimize a line by looking at buffer sizing and machine group efficiencies. Also some modeling of different lines was performed in order to determine the most efficient line. The implementation process followed by this company compared to the Hypothesized Lean Implementation Model is shown in Figure 15.

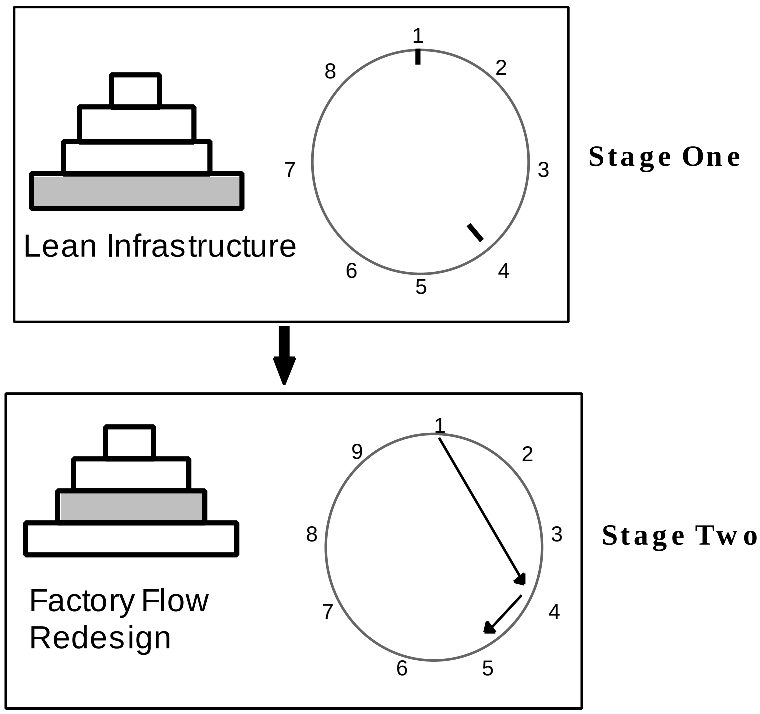


Figure 15: Case Study Number Eleven Implementation Sequence

Case Study Number Twelve

The proposed framework and case study performed in this thesis shows only two out of the four phases of the hypothesized Lean Implementation Model. The case study touches sections of phase 1 and phase 4. This may be due to the type of product manufactured in this company. However it is noted that this Lean Implementation Model can also be used in other industries that are not discretely manufacturing. Figure 16 illustrates the implementation sequence followed.

In stage one, the company started by establishing an environment and structure which recognized the need and importance of process improvement. It also defined the areas for improvement and prioritized those with obtainable goals. After the strategy was developed and it identified their current and needed skills, it started implementing the ideas into the process. During the second stage, this company only used three practices; however, they achieved most of their goals.

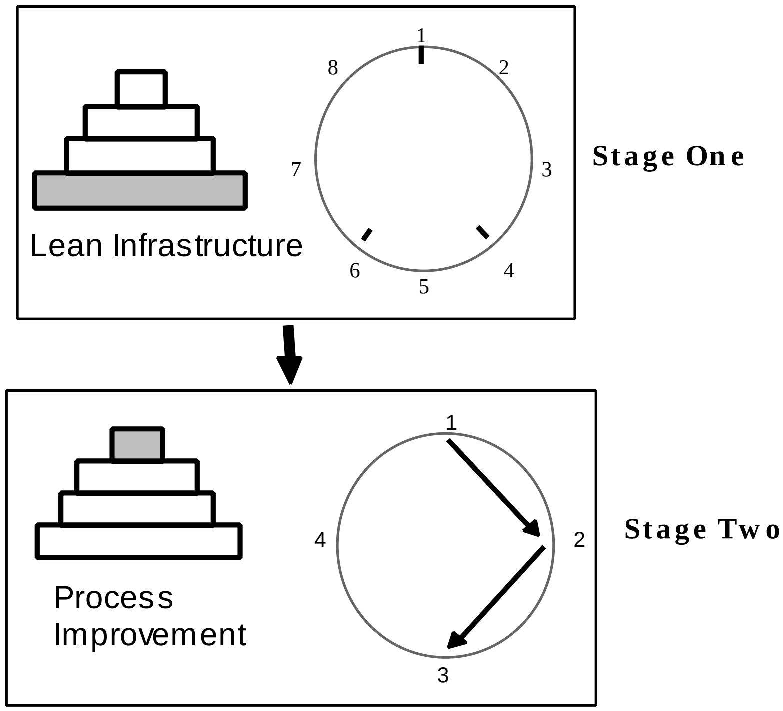


Figure 16: Case Study Number Twelve Implementation Sequence

Analysis

From the previous section there are a total of twelve case studies. Using the hypothesized Lean Implementation Model, a summary of the results is provided in Table 1. This table lists the four phases of the model. From the results of the case studies the stage (order) in which a phase was implemented in the case study is indicated in a box to the right of the phase name. Remembering that the lean infrastructure and operations management phases of the implementation model do not specify the order of implementation, the boxes are marked with an “X” rather than a sequence number. Since the factory flow redesign and process improvement phases do specify order, the order of implementation is depicted in the table. In some cases, phases were repeated twice. In these cases, the column is split with the left of the split indicating the first stage in which this phase was observed and the right split indicating the second stage in which this phase was observed.

Steps Used (order specified if pertinent to phase)	Case Study #1		Case Study #2	Case Study #3		Case Study #4		Case Study #5		Case Study #6	Case Study #7	Case Study #8	Case Study #9	Case Study #10	Case Study #11	Case Study #12
Phase 1 Lean Infrastructure	Stage 1 Stage 3		Stage 1	Stage 1 Stage 3		Stage 1		Stage 1		Stage 1			Stage 1	Stage 1	Stage 1	Stage 1
Step #1	X	X	X		X	X		X		X			X	X	X	X
Step #2	X		X		X	X				X						
Step #3	X	X			X											
Step #4	X	X		X	X	X							X		X	X
Step #5		X	X	X	X	X										
Step #6	X				X	X		X		X						X
Step #7	X	X			X											
Step #8		X	X	X	X											
Phase 2 Factory Flow Redesign	Stage 2		Stage 2	Stage 4		Stage 2 Stage 3		Stage 2		Stage 2		Stage 1			Stage 2	
Step #1			5	1			1			1					1	
Step #2	1		1	2				1		2		1				
Step #3	2		2	3		2						3				
Step #4			3			1		2		3		2			2	
Step #5	3		4	4			2	3				4			3	
Step #6	4		6	5		3	3			5						
Step #7																
Step #8	5		7	6						4						
Step #9	6		8				4			6		5				
Phase 3 Operations Management Development	Stage 3		Stage 2	Stage 2 Stage 4		Stage 2 Stage 3		Stage 2 Stage 4		Stage 2						
Step #1	X		X	X	X	X	X			X						
Step #2	X		X	X	X	X	X									
Step #3						X		X								
Step #4							X		X	X						
Phase 4 Process Improvement	Stage 4		Stage 3	Stage 5		Stage 4		Stage 3		Stage 3	Stage 1		Stage 2	Stage 2		Stage 2
Step #1	1		1	1						1	1		1			1
Step #2	2		2	2		1					2		2	1		2
Step #3								1			3					3
Step #4			X			2					4			2		

Table 1: Summary of the Case Studies using the Hypothesized Lean Implementation Model Framework

Using the results from the Table 1, further analyses on each of the phases of the hypothesized Lean Implementation Model were accomplished using each case which used this phase. Starting with the lean infrastructure phase and going up in the model to the process improvement phase, each phase is analyzed to understand the extent of usage of the phase model in general and then to analyze the particular steps that were observed to have been used in the case studies.

In the lean implementation phase of the hypothesized model, there were nine cases where this phase use was observed. In two cases the phase was revisited after initially addressing some of the phase steps. In these two cases the missing steps from the first implementation stage were implemented when the phase was revisited. In one case, all steps were addressed when the phase was revisited. Table 2 shows the results of the analysis of the number of steps used by the nine case studies that addressed lean infrastructure. Each of the cases used at least one step and most of the cases used at least three of the lean infrastructure steps. In those cases where the lean infrastructure phase was revisited, there is a definite increase in the number of steps implemented. This result indicates that the lean infrastructure phase was revisited because the first implementation did not succeed in establishing a significant base for further lean improvements. This observation is important because there appears to be significant lean infrastructure steps that need to be accomplished before other lean changes (i.e. the other phases of lean implementation) can be executed well.

Number of Phase Steps Used	After First Stage of Implementation (%)	After Second Stage of Implementation (%)
1	100	100
2	89	89
3	56	56
4	33	44
5	22	33
6	11	22
7	0	22
8	0	22

Table 2: Extent of Steps Used in the Lean Infrastructure Phase

We captured the steps of the lean infrastructure phase that were most often used by the case study sites. Table 3 reflects this information showing the percentage of the case study sites that used a specific step in the infrastructure phase. Although we do not feel that the frequency of specific step use is a reliable indicator of the significance of that step, it does provide information about which steps companies typically initiated as they began lean implementations. As can be seen from the table the most used steps in descending order were:

- Identify business issues/goals and develop a strategy
- Identify current and needed skills
- Breakdown stovepipe mentality

- Perform benchmarking (tied)
- Fill skill gaps with corporate wide training (tied)

- Establish linkages with supplier and customer base

- Develop an information technology hardware and software strategy (tied)
- Assess technology impacts (tied)

Specific Steps Used by each of the Case Study Sites	After First Stage of Implementation (%)	After Second Stage of Implementation (%)
Step #1	89	100
Step #2	33	44
Step #3	11	22
Step #4	67	67
Step #5	33	44
Step #6	44	56
Step #7	11	22
Step #8	22	33

Table 3: Specific Lean Infrastructure Steps Used by Case Study Sites

In the Factory Flow Redesign Phase there were eight cases where the phase was used at least once in the lean implementation. One case revisited the phase again. In this phase, we hypothesized an order to the implementation sequence. We found that four of the eight cases followed the order (even though some of the steps may have been skipped). The phase diagrams were analyzed to see which sequence was the predominant sequence. Figure 17 reflects this analysis. The arrows reflect the predominate sequence observed from the case studies. The numbers on the interior of the circle indicate the number of cases that this sequence was followed. Therefore, the predominate sequence (in order) is indicated to be:

- Distribute information
- Group products into families
- Design process layout and simulate flow
- Optimize factory flow and cell linkages
- Redefine and redeploy work tasks
- Construct cells through *Kaizen* events (tied)
- Make product flow visible within the cell (tied)

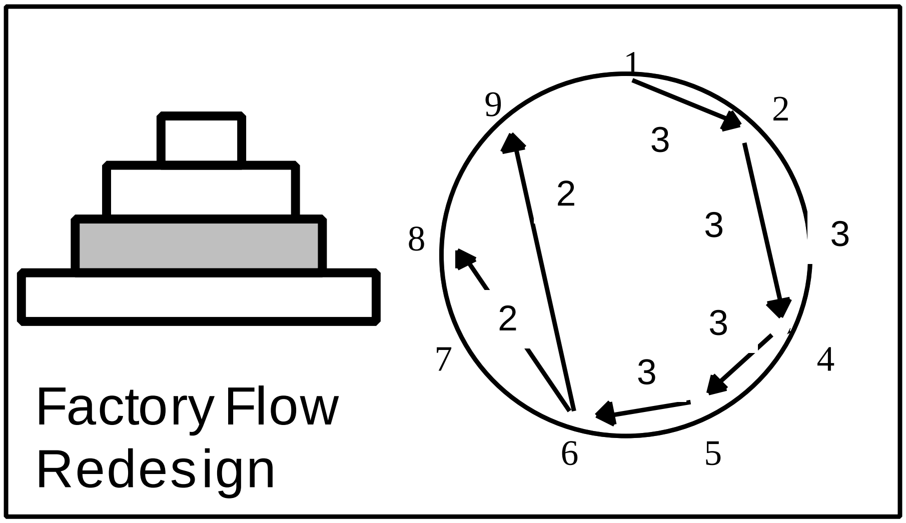


Figure 17: Factory Flow Redesign Predominant Sequence

Table 4 shows the results of the analysis of the number of steps used by the eight case studies that addressed factory flow redesign. Each of the cases used at least three steps and most of the sites used at least six of the factory flow redesign steps.

Number of Phase Steps Used	After First Stage of Implementation (%)	After Second Stage of Implementation (%)
1	100	100
2	100	100
3	100	100
4	63	75
5	63	75
6	50	50
7	13	13
8	13	13
9	0	0

Table 4: Extent of Steps Used in Factory Flow Redesign Phase

We captured the steps of the factory flow redesign phase that were most often used by the case study sites. Table 5 reflects this information showing the percentage of the case study sites that used a specific step in the factory flow redesign phase. Although we do not feel that the frequency of specific step use is a reliable indicator of the significance of that step, it does provide information about which steps companies typically initiated as they began lean implementations. As can be seen from the table the most used steps in descending order were:

- Optimize factory flow and cell linkages

- Group products into families (tied)
- Design process layout and simulate flow (tied)

- Distribute information (tied)
- Standardize processes (tied)
- Redefine and redeploy work tasks (tied)

- Construct cells through *Kaizen* events (tied)
- Make product flow visible within the cell (tied)

Specific Steps Used by each of the Case Study Sites	After First Stage of Implementation (%)	After Second Stage of Implementation (%)
Step #1	50	63
Step #2	75	75
Step #3	63	63
Step #4	75	75
Step #5	75	88
Step #6	63	63
Step #7	0	0
Step #8	50	50
Step #9	50	50

Table 5: Specific Factory Flow Redesign Steps Used by Case Study Sites

In the Operations Management Phase of the hypothesized model, there were six cases where this phase was observed. In three cases the phase was revisited after initially addressing some of the phase steps. In these three cases where the phase was revisited, usually the same steps were revisited. In one case, all steps were addressed in the two times that the operations management development phase was implemented. Table 6 shows the results of the analysis of the number of steps used by the six case studies that addressed operations management development. Each of the cases used at least two steps (after revisiting the phase).

Number of Phase Steps Used	After First Stage of Implementation (%)	After Second Stage of Implementation (%)
1	100	100
2	83	100
3	17	33
4	0	17

Table 6: Extent of Steps Used in Operations Management Development Phase

We captured the steps of the Operations Management Development Phase that were most often used by the case study sites. Table 7 reflects this information showing the percentage of the case study sites that used a specific step in the operations management development phase. Although we do not feel that the frequency of specific step use is a reliable indicator of the significance of that step, it does provide information about which steps companies typically initiated as they began lean implementations. As can be seen from the table the most used steps in descending order were:

- Cross-train workers and realign incentives
- Reallocate support resources
- Implement "pull" production systems
- Implement manufacturing information systems

Specific Steps Used by each of the Case Study Sites	After First Stage of Implementation (%)	After Second Stage of Implementation (%)
Step #1	83	83
Step #2	67	67
Step #3	33	33
Step #4	17	50

Table 7: Specific Operations Management Development Steps Used by Case Study Sites

In the process improvement phase of the hypothesized model, there were ten cases where this phase use was observed. In one case, all steps were addressed. We found that all of the cases followed the order (even though some of the steps may have been skipped). The phase diagrams were analyzed to see which sequence was the predominant sequence. Figure 18 reflects this analysis. The arrows reflect the predominate sequence observed from the case studies. The numbers on the interior of the circle indicate the number of cases that this sequence was followed. Therefore, the predominate sequence (in order) is indicated to be:

- Improve process and operations predictability
- Improve process quality

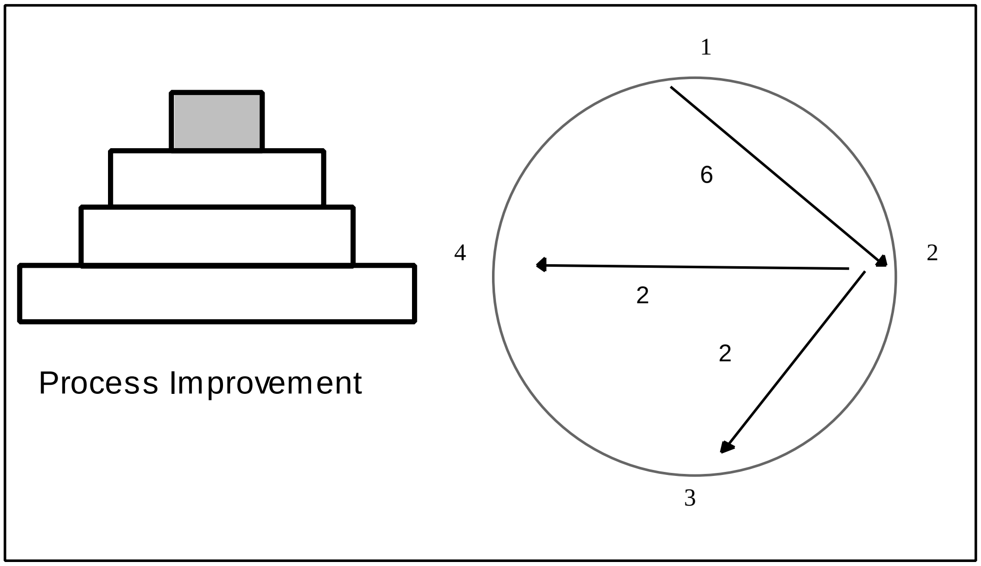


Figure 18: Process Improvement Predominate Sequence

Table 8 shows the results of the analysis of the number of steps used by the ten case studies that addressed process improvement. Each of the cases used at least one step and most of the sites used at least two of the process improvement steps.

Number of Phase Steps Used	After Implementation (%)
1	100
2	80
3	30
4	10

Table 8: Extent of Steps Used in Process Improvement Phase

We captured the steps of the process improvement phase that were most often used by the case study sites. Table 9 reflects this information showing the percentage of the case study sites that used a specific step in the process improvement phase. Although we do not feel that the frequency of specific step use is a reliable indicator of the significance of that step, it does provide information about which steps companies typically initiated as they began lean implementations. As can be seen from the table the most used steps in descending order were:

- Improve process and operations predictability
- Improve process quality
- Increase process speed
- Increase process flexibility

Specific Steps Used by each of the Case Study Sites	After Implementation (%)
Step #1	80
Step #2	70
Step #3	30
Step #4	40

Table 9: Specific Process Improvement Steps Used by Case Study Sites

The order of implementation of each of the phases was captured in Table 1 using the stage annotation in the phase row. This information is summarized in Table 10. The order of implementation as compared to the hypothesized model is captured in Figure 19. The numbers to the right and left of the implementation phase name indicates the order of implementation relative to the number of case studies compared (for instance 10/12 indicates the order of implementation of this phase occurred in 10 of the 12 cases). Two separate groupings of cases were considered: (1) all case studies and (2) the first seven case studies. The first seven case studies were the most exhaustive case studies which considered the total lean transition observed at the case study site. In case studies 8-12, the source material was detailed studies of specific focused transitions which did not consider other aspects of changes occurring at the case study site. The numbers displayed for the operations management development phase reflect those implementations that occurred third in sequence or concurrently with factory flow redesign.

Case Study	1	2	3	4	5	6	7	8	9	10	11	12
Lean Infrastructure	1 3	1	1 3	1	1	1			1	1	1	1
Factory Flow Redesign	2	2	4	2 3	2	2		1			2	
Operations Management Development	3	2	2 4	2 3	2 4	2						
Process Improvement	4	3	5	4	3	3	1		2	2		2

Table 10: Order of Implementation of the Phases in Case Study Sites

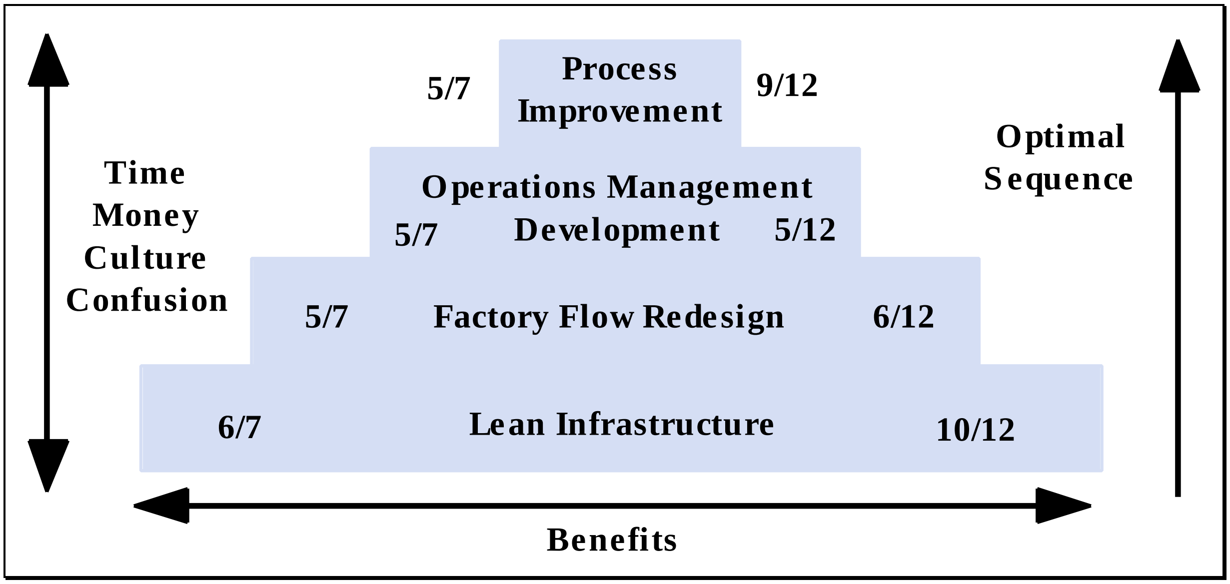


Figure 19: Implementation Sequence of the Case Studies Compared to the Hypothesized Lean Implementation Model

Conclusion

The research team was able to identify twelve case studies to compare to the hypothesized lean implementation model. Of these twelve case studies, the first three were accomplished after the development of the hypothesized lean implementation model. The researcher had the advantage of a framework to assess the lean transition studied in these case studies and could specifically address questions that would assist in the comparing of case study circumstances to the hypothesized lean implementation model. Case studies four through seven were thorough case studies performed before the creation of the hypothesized lean implementation model. These case studies had a broad focus and were able to capture the enterprise aspects of the lean transition. Therefore, the first seven case studies were very exhaustive case studies that considered enterprise-wide aspects of the lean transition. In case studies eight through twelve, the focus was on particular implementations and did not consider the entire enterprise in the analysis. Although the entire enterprise may not have been considered, important information was obtained on the steps and sequence of steps in a particular phase of the hypothesized lean implementation model. Therefore, we conclude that case studies one through seven give the best analysis of the implementation sequence for the phases of the hypothesized lean implementation model and all the case studies can be used for the analysis of the individual phase's implementation sequences.

During and after the conduct of the case studies, it was difficult to separate specific implementation steps. Many changes were happening at the same time. This ambiguity was addressed in the model depiction with simultaneous implementations in the same stage. The researchers also found that the steps within a particular phase could not be characterized with normal start and stop types of categorizations. Instead many of the implementations had multiple steps in different phases being implemented concurrently. Many steps continued to be addressed long after another phase of the hypothesized lean implementation model was being addressed. The researchers made their best judgment about the order of initiation of implementation steps. However, it cannot be ruled out that the investigators were biased by the hypothesized lean implementation model. Therefore, despite the use of a framework and its definitions, there is significant ambiguity in interpreting the transition steps from observations and there is possible researcher bias in the categorizing of these results.

The limited number of case studies, the focus on the defense aircraft industry lean transitions rather than all industry lean transitions and the lack of a consistent implementation strategy coming from this limited analysis all indicate that the hypothesized lean implementation model is not sufficiently tested to be accepted as a lean implementation model. Despite these shortcomings, we feel that the observations using the hypothesized lean implementation model as a framework does offer some useful insights.

The analysis of the lean infrastructure phase of the hypothesized lean implementation model indicates that at least three phase implementation steps were used in more than half of the case studies. In two cases, the phase was repeated. Each time more steps were accomplished and a broader base established for a lean infrastructure. The hypothesized lean implementation model postulates that the advantage of subsequent phases can be limited by the degree of implementation of the preceding phase. There appears to be some support for this contention based on the need to revisit the lean infrastructure phase. In the two instances where this phase was revisited, increased emphasis was placed on training and achieving a self directed workforce respectively to allow further lean improvements (see case studies one and three for details). The specific steps implemented in more than half of the case studies were:

- Identify business issues/goals and develop a strategy
- Identify current and needed skills
- Breakdown stovepipe mentality

The factory flow redesign phase of the hypothesized lean implementation model postulates an order of step implementation. The analysis of the case studies indicates agreement with this hypothesis in that the predominate sequence was the following:

- Distribute information
- Group products into families
- Design process layout and simulate flow
- Optimize factory flow and cell linkages
- Redefine and redeploy work tasks

At least six phase implementation steps were used in half of the case studies. All nine of the implementation steps were used by at least half the case study sites. There was one step that was not credited as being accomplished in any of the case study sites: delegate authority and accountability. We did observe several instances where the degree of ownership of the processes necessary to produce the product had a large impact on improvements. While this step does not appear to be supported by these case studies, we suspect a larger sample of case studies would support this step as well.

The operations management development phase of the hypothesized lean implementation model was observed in only six of the twelve case studies. In those cases where it was observed, each used at least two of the four steps in the phase. At least half used the following specific steps:

- Cross-train workers and realign incentives
- Reallocate support resources
- Implement “pull” production systems

An order to the implementation steps was postulated in the process improvement phase lean implementation model. Based on the analysis of the case studies, there is good agreement in doing the first two steps: (1) improve process and operations predictability and (2) improve process quality. The third step is ambiguous because results are split between doing the two remaining steps, i.e. increase process flexibility and increase process speed.

The implementation sequence for the four phases of the hypothesized lean implementation model using the seven cases that consider enterprise level implementations tends to support the hypothesized model. The lean infrastructure phase was initiated first in 86 percent of the studies. The remaining phases followed the order of the hypothesized model in 71 percent of the studies. The implementation of the lean infrastructure phase and the process improvement phase were most unambiguous usually being initiated first and last respectively. The factory flow redesign and operations management development phases, however, were less definite with five of the seven cases featuring simultaneous implementations. The extent of the simultaneous implementation of these phases indicates a certain ambiguity to the order of implementation of these two phases. This ambiguity about the order of these two phases was also discussed among the researchers when the hypothesized model was developed. Therefore, the order of the two center phases (among themselves) in the hypothesized model should not be considered order dependent.

Based on strong evidence from three of the case studies, the degree of process ownership by the manufacturing management, the self directed work teams or both together was a critical factor in successful lean transformations. When the product had to be released to other manufacturing areas and control was lost the degree to which lean improvements could be accomplished was reduced. Based on this finding, we would make several changes to the wording of two of the hypothesized model steps:

- Phase 1.6 Breakdown stovepipe mentality and establish cross functional linkages: add the following sentence to the first paragraph, "Strive to give those individuals that are responsible for the product as much of the process ownership as possible."
- Phase 2.7 Delegate authority and accountability: add the following sentence to the description, "Give those individuals that are responsible for the product as much of the process ownership as possible."

The hypothesized model was designed for lean implementation guidance at the factory operations level. As such, many enterprise practices were not included. From many of the case studies, however, we found that change did not happen without the leadership of a champion or senior management. The absence of a specific step on leadership from our model is not intended to suggest that it is not important. It may instead be a prerequisite before lean transitions can be accomplished.

There remain a number of factors that make it difficult to assess the viability of our proposed Lean Implementation Model. First, we do not feel that the evidence based on the case studies is overwhelming. The case study sites themselves may not be characterized as being the best examples available of lean implementations. Therefore, the case studies may not have captured the epitome of a lean implementations. Many of these case study sites however, were sites recognized within the Defense Aircraft Industry as having accomplished small scale lean transitions. The researchers themselves had to make subjective determinations to interpret events at a particular case study sites and researcher bias is possible in attributing specific actions to steps in the model.

Despite the shortcomings to this study, we feel that the model offers a general guide for structuring a strategy for lean implementation in the defense aircraft industry. Therefore, we feel that the hypothesized model can be a useful reference for members of the Lean Aircraft Initiative to use in the planning and execution of their lean transitions. However, we acknowledge that the lack of a consistent pattern in our case studies may suggest that there are multiple ways to achieve the same objective.

Appendix A: Case Study Number One[20]

Introduction

This case study is of a major defense aircraft company in the airframe sector of the Lean Aircraft Initiative. The product which is the focus of the study is a large structure that is part of a fighter aircraft. This case study was based on the lean practices employed on two versions of this product. The first version was produced before the advent of lean practices and the second version incorporates changes that were influenced by lean practices.

This case is worthy of study because there was a lean transition that occurred which produced significant benefits to the company. Corrective Action Request (CAR) reports, which identify manufacturing problems, indicate that the manufacturing performance was significantly better in the line producing under lean ideas than the older line. Assembly hours were reduced by 19 percent from comparable shipset serial numbers on the old line. The number of defects were reduced in half by the fifth aircraft shipped compared to the old line.

Total Transition Implementation Sequence

The following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix A Figure 1 shows the process or sequence followed. Each box or level in the diagram represents a stage of lean implementation.

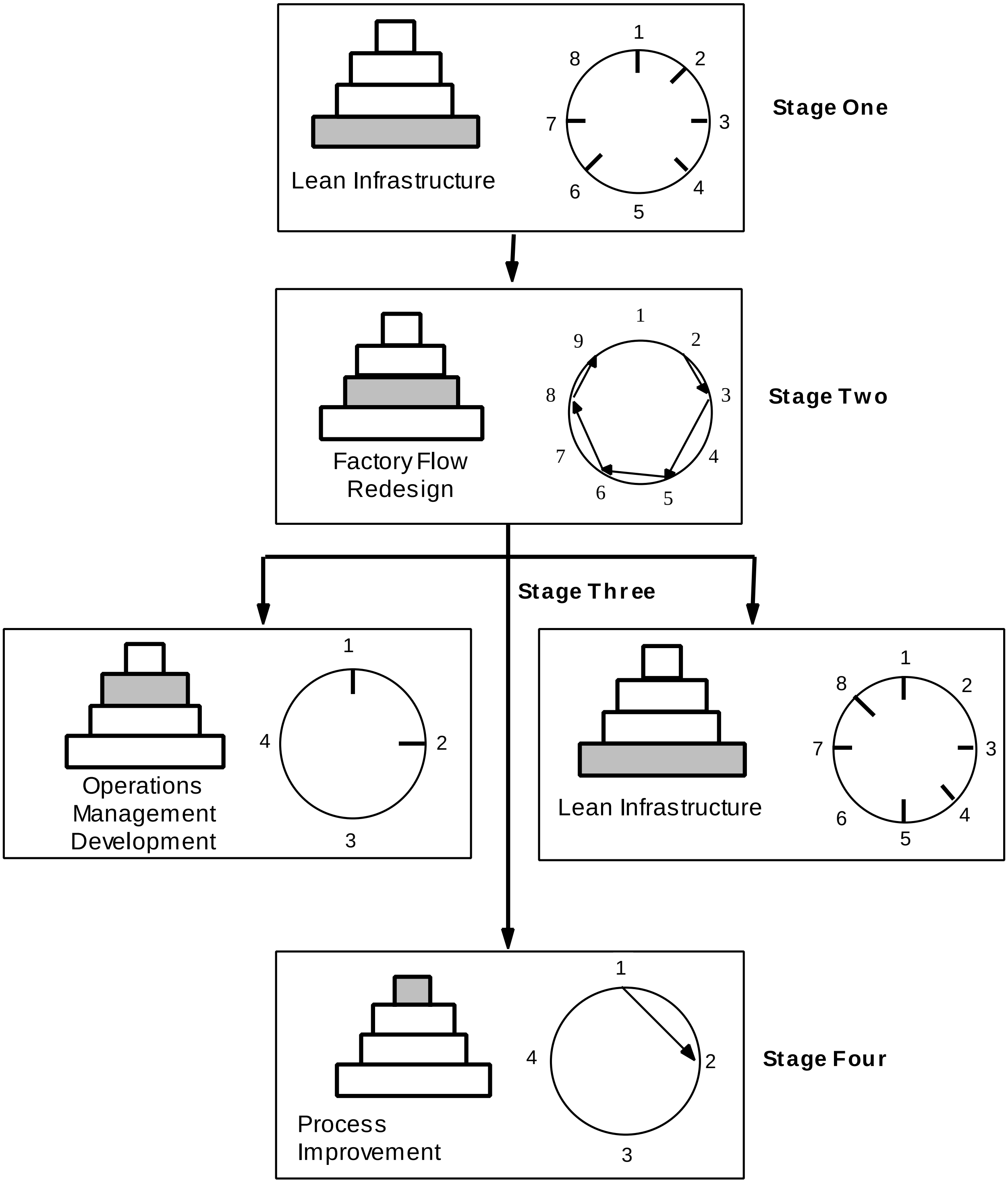
In the first stage of lean implementation the company sought long term infrastructure changes based on a set of corporate goals and an implementation strategy. This was reflected in strategic decisions about core competencies to be pursued. These decisions impacted the skill needs of the company. Although benchmarking was performed, it was focused on the area which was eventually outsourced. One of the strengths noted was a very determined effort to develop an information system that used a common, open system architecture to replace many legacy systems. This open architecture system improved information availability to all who needed it. Another tenet in this stage was the transition from a functional organization to a programmatic team-based operation structure. In this stage, Integrated Product Teams (IPTs) were used on new programs while older programs retained their functional organizational structure. Also in this newer program, technology solutions like common design tools among major suppliers were mandated.

[20] This case study is based on the case study reported in the Massachusetts Institute of Technology thesis by Michael John Pozsar, "Application of the Lean Aircraft Initiative Factory Operation Model to Case Studies in the Defense Aircraft Industry," 1996.

In the second stage of lean implementation the primary emphasis was on factory flow redesign. Many of the factory changes were incorporated in the company's new program. The production of subassemblies for the assembly line was moved to be adjacent to the assembly line. With this coupling, subassembly starts were linked to the assembly line needs and delivered to the assembly line when needed rather than being delivered to storage. Many process steps were standardized and deployed for better product flexibility.

The third stage of the lean implementation reflects the learning that occurred with the two previous stages. For instance, virtually all items in the lean infrastructure phase were revisited during this stage. It is significant to recognize that the missing elements from the hypothesized model from stage one were addressed in this stage. In particular, to support the new program, a company wide training program was initiated for assembly line workers. Expanding the IPT concept to suppliers was a natural progression in this phase. Simultaneously, Operations Management Development items were pursued to cross-train workers and to reallocate support resources (including supplier resources).

Finally, the last stage reflects the process improvements effected to improve the quality of the product. These efforts were primarily focused on reducing the process variability and improving the quality of close tolerance holes in the product.



Appendix A Figure 1: Case Study Number One Implementation Sequence

Stage One

Implementation of Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy:

The operating strategy is rooted in a corporate wide architecture plan which was developed in the mid 1980s. This strategy was originally initiated to address: 1) concerns over the division's increasing investment requirements in information technology and, 2) the organization's loss of competitiveness. The resulting plan, however, addressed more than information systems. It envisioned an operating culture that described MRP, the Factory of the Future, Centers of Excellence, processes surrounding product definition and concurrent engineering. The plan was used on several programs before our study and further expanded upon in the 1993 manufacturing plan of the program which we studied.

Many of the practices described in the manufacturing plan have formed the cornerstone for the lean transition on the newer line. In addition to this effort, the older program also began to initiate a Manufacturing Process Variability Reduction (MPVR) program in 1991-92. This program supplemented government requirements to implement top-level TQM practices and was carried over to the newer program. MPVR is an organized, systematic approach for accomplishing variability reduction using process improvement and control methodologies. Its wide ranging objectives include the following: reduce cost and delivery time; improve product quality, customer satisfaction and competitive position; provide process capability information and; transition from an inspection oriented to a process control oriented method of operation. MPVR represented a major change in the organization's operating culture. While good quality and zero defects have always been common manufacturing goals, historically the emphasis was on cost and schedule. Employee empowerment and process ownership are critical to the successful achievement of any of the MPVR implementation plans

Phase 1.2 Perform benchmarking:

Before the company decided to outsource its machining and sheet metal fabrication in 1993, it had conducted a number of benchmarking trips to learn methods of improving its processes. Many of the practices observed on those trips were used to redesign the fabrication plant factory flow.

Phase 1.3 Develop an information technology hardware and software strategy:

The implementation of the company's MPVR program included significant changes to the organization's information systems strategy. The organization's long-term goal was to replace its mainframe legacy systems with a common open systems client/server architecture that utilizes commercially available off-the-shelf applications software. Included in the MPVR program's goals for 1995 was the migration of the current SPC system to a UNIX/Oracle platform using RISC computers instead of personal computers. In conjunction with the SPC transition, the company also planed to acquire and initiate the development of a Manufacturing Process Data Base System (MPDB). The MIS group planned to implement common hardware, software and networking equipment across the enterprise utilizing an open systems platform architecture. Their systems implementation strategy was to procure as much commercially available software as possible in order to minimize in-house proprietary software development. Internal software development required tremendous resources in personnel and time and may not provide significant operating advantages.

There were a few weaknesses with the information system that were observed. The company currently uses a separate timekeeping and earned value system. Therefore, it required a manual paper operation to correct mistakes on a daily basis and it was a time consuming manual process to provide operations management with how much was spent by cost center, by individual, by tool on a daily basis. The information that was currently available may not be accurate. The two systems are planned to be linked electronically in the future.

A policy weakness that existed is the large variability in reporting requirements from various managers. Charts and reports that are designed to suit individual preferences (both internal and exterior to the company preferences) created significant non-value-added work associated with input and format generation, especially if the system was not user-friendly. Standardized reporting formats with common performance metrics could be utilized to support organizational objectives and to simplify the low-value-added report generation process.

The company costing system may also be inadequate to base strategic decisions. The costing system played a role in the company's decision to outsource fabrication. Overhead charges were disproportionately allocated to fabrication. This prevented the machine shop from successfully competing with external suppliers that did not have large overhead charges.

Phase 1.4 Identify current and needed skills:

The MPVR program provided the focus for the company as it identified its workforce competency and skill requirements. This program has put a premium on the use of statistical methods for process improvement. Accordingly, the company sought to exploit current expertise and expanded this expertise in its workforce.

Phase 1.6 Break down stovepipe mentality:

The IPT concept used in the new line was driven by both the company's CEO and their customer's program specifications. There were five major product oriented IPTs on the new line instead of the functional organization used on the older line. IPTs were created at different management/personnel levels: level four - team; level two and level three - team leaders; level one - program managers and others as needed. A level four IPT was composed of a product design engineer, manufacturing engineer (responsible to operations), tool designers, procurement specialists, offsite manufacturing engineers (responsible for suppliers), planners and expediters. Each IPT had a number of related subassembly and main assembly line cost center personnel assigned to it and each team program manager was responsible for quality, cost and schedule. The older program did not utilize IPTs and therefore the transition between product design, manufacturing engineering and operations was more difficult.

Included in the company's Manufacturing Process Variability Reduction (MPVR) plan was its definition of the roles and responsibilities of product definition IPT and product delivery IPT and those activities that had joint ownership. This definition improved the new line's transition from design to manufacturing. One of the challenges in this new system, however, was to modify the operating environment in order to better define the tradeoff in responsibilities between functional departments and integrated product teams.

Phase 1.7 Assess technology impacts:

All product and manufacturing design was specified by the customer to utilize UGII CAD systems for development of the newer product. The UGII was cited as one of the most important enablers to the success the company has experienced in its process variability reduction plan. The company effectively applied tolerance stack-up and product variability analysis tools to reduce process variability and significantly improve first time capability. Tooling engineers used UGII part data to develop and simulate tooling designs concurrent with product designers. UGII significantly reduced feedback lead-times between the two groups which enabled product designers to incorporate manufacturing concerns and requests into their designs. Three dimensional CAD data was critical to the successful first-time assembly of subassembly hydraulic tubing and other peripheral support system designs that traditionally applied craftsman fit-at-assembly skills. The right hardware and software enabled the company to achieve a Design-For-Manufacturing/ Assembly (DFM/A) environment.

The company used some process technology to assist in the manufacture of composite tooling. Automated Tool Manufacture for Composite Structures (ATMCS) is a software product developed by the company under a United States Air Force contract from 1990 to 1994. This software product significantly improved first time process capability and reduced overall tooling development lead-time. It has composite tool design macros that converts UGII and CATIA part data into "best" eggcrate or other structural tool design. The expert knowledge for the system was the result of an industry survey (1990-93) on the best composites tooling design practices from a number of leading composite manufacturers. This product was used to successfully design 105 production tools on the newer program at a $4 million savings to budget and 65 percent ahead of schedule condition.

Other process technologies were also used. ESP (Expert Systems Planner) is a software product developed in the late 1980s to expedite tube and weld manufacturing planning. This product assists designers in generating complete manufacturing process plans and work orders from a part description. The successful application of this product reduced planning lead-times by 90 percent on the newer program.

Stage Two

Implementing Phase 2 - Factory Flow Redesign

Phase 2.2 Group products into families:

One of the significant layout characteristics of the newer production line is the collocation of subassembly lines with the main assembly line. In this sense, the subassemblies were linked directly with the main assembly floor requirements and improved the flow of the assemblies.

Phase 2.3 Standardize processes:

The development of the new assembly line allowed the company to work out any problems experienced on the older line and transfer this learning to the newer line. For example, structural assembly of skins, bulkheads, longerons, etc. was completed at an earlier stage on the newer assembly line than it was on the older line for the following reasons:

1. The assembly of structural components at an earlier operation on the assembly line enabled the reduction of Foreign Object Debris from 100 pieces per shipset on older line to approximately 0.1 pieces per shipset on the newer line. This result was due to a reduction in the number of low visibility physical locations where debris had traditionally collected on the older line.
2. Subsystems were modified or redesigned more frequently than the overall structure changes therefore, it was commonsense that product areas requiring increased flexibility be located as close as possible to the last operation on the assembly line. Problems associated with variable product options can be minimized if the assembly of options is located closer to the end of the assembly line than the beginning.
3. Earlier assembly of the standard structural components implied that less subsystems infrastructure (i.e., hydraulics, electrical, etc.) work-arounds were required.
4. International customers were sometimes allowed to execute offset contracts which transferred some of the assembly processes and the custom installation of their own subsystems at their location.
5. Fewer small components are damaged if the small components are assembled after the large structural parts are already assembled.

Phase 2.5 Optimize factory flow and cell linkages:

Since subassemblies were not started until a lead-time away from the main assembly line, the subassemblies did not go to a crib for storage or require retrieval. This action provided the company with major benefits. First, the lot sizes used in most subassembly cost centers was limited to one unit. In the older program multiple units were built. The elimination of the subassembly inventory crib reduced subassembly WIP inventory by approximately 60 days. In the older program, extra components were simply sent to the crib.

Another example illustrating the transfer of experience from the older line to the newer line was the process and tooling design for the last three operations. On the older line, the shipset is moved to a different fixture on a rail system. Even though the same datums may be used, fixture variability from station to station becomes “built into” the final product. In order to reduce tool-to-part variability on the newer line, the shipset was not removed from the holding tool. The holding tool and product are transferred together from station to station. The newer line holding tool was mounted on air bearings that allow the shipsets to be moved more easily which also minimized overhead crane requirements on the assembly line.

Phase 2.6 Redefine and redeploy work tasks:

The close linkage of subassembly to the assembly line required the redefinition of operating methodology. This coupled with the changes to accommodate SPC use in hole drilling support this phase's activities.

Phase 2.8 Construct cells through *kaizen* events:

Although *kaizen* events were not specifically used, the implementation of subassembly collocation to the assembly operation was an initiative of the floor operations personnel. This alignment of subassembly work close to the assembly line improved communication, reduced the transfer of subassemblies into storage and reduced the distances that the subassemblies needed to travel between stations.

Phase 2.9 Make product flow visible within the cell:

The reduction of lot sizes to one unit in the subassembly area promoted the application of visual management practices. The company planned to implement a "pull" inventory system using WIP inventory as the visual control mechanism in the future.

Stage Three

Implementing Phase 3 - Operations Management Development (concurrent implementation)

Phase 3.1 Cross-train workers and realign incentives:

In addition to other certification programs, Statistical Process Control was a required training course for all mechanics who collected or utilized SPC data. The shop floor computer system would not allow mechanics to log on to a job requiring SPC data collection unless the appropriate level of certification had been achieved. The successful implementation of these processes, along with the fulfillment of contract requirements, guided the program. There were two major assembly operator classifications: subsystem mechanics and structural mechanics. Both classifications received the same training. Employees within cost centers are cross-trained. This increases management's flexibility in satisfying variation in the build schedule. The newer line workforce received more training than the older line workforce and can therefore handle greater production variability. The newer line employee responsibilities were expanded to include the cleanliness of their work areas. It was believed that this contributed to the success of the Foreign Object Elimination (FOE) program.

Considering the employee incentive structure, the mechanism for rewarding outstanding achievement limited the potential benefits associated with IPTs. Changes in the remuneration system lagged changes in the functional operating environment. Hence, the current incentive system did not support the operating behavior that the company wanted to achieve.

In addition, as the organizational structure continued to flatten, there were fewer hierarchical promotional opportunities for which individuals can aspire. Management recognized that greater horizontal mobility and promotion would need to be incorporated in this structure in order to align personnel incentives with performance. These changes were not yet observed.

Phase 3.2 Reallocate support resources:

As part of the execution of the company's strategy to focus on composites fabrication, it has recently outsourced virtually all of its non-composites related fabrication capabilities and requirements. The decision to outsource fabrication was made largely on economic grounds. In this case, the removal of all metal fabrication and the establishment of teams as the dominant organizational structure has effectively forced the reallocation of resources within the company. There are several other aspects of operations management that have also been accomplished.

The company initiated four major processes that support the transfer of quality assurance responsibilities from the quality control department to the assembly department. The transition from an inspection oriented to a process control oriented operation resulted in a savings of $3.5 million in another division of the company. During this 3-4 year process, employees undergo an internal training program in order to receive Product Assurance Personnel Certifications from the American Society of Quality Control. Before quality assurance responsibilities were transferred to the employee, the Quality Control department continues to monitor employee performance until the employee achieved a 99.5 percent process yield. The company adopted a Certified Assembly Mechanic (CAM) program that was jointly developed with a local community college. Hole processing training, however, occurred on-the-job because class-room hole-processing on flat surfaces was not comparable to the real-world process completed on curved surfaces on the main assembly line.

Implementing Phase 1 - Lean Infrastructure (concurrent implementation)

Phase 1.1 - Identify business Issues/goals and develop a strategy:

The corporate manufacturing strategy focused on composites fabrication and airframe assembly. Executive management made significant investments in composites manufacturing processes in order to become one of the premier composites fabrication companies in the airframe industry. Since the technological development of new airframes was demanding an increasing proportion of lighter weight and higher strength composites materials, one of the company's objectives was to exploit its core competence in composites manufacturing technology as a source of competitive advantage in the competition for future airframe contracts.

Another corporate goal was to receive ISO 9000 certification. The specific requirements defined by this certification include the implementation of concepts like IPT and multi-skill job training programs which reinforce the company's efforts in these areas. The adoption of this objective reinforced the program's vision for all employees and clearly specified the performance and operating requirements necessary to attain this level of certification. Since the organization began rallying around the attainment of these objectives, a "new" operating atmosphere or culture based on change and continuous improvement began to be infused into the firm.

Phase 1.3 - Develop an information technology hardware and software strategy:

As a continuation strategy the company implemented a pseudo method of capturing activity based costs using one additional field in their current cost accounting system. The Cost of Quality information system was driven by the requirement to provide more relevant and timely information for management decision making. The current accounting system could not provide the required information in a timely fashion and the transition to an enterprise wide Activity Based Counting (ABC) system was not supported by current final customer policy and contracts. Consequently, the organization began implementing its own Cost of Quality program in January 1996. The focus of this system was on capturing cost data in five categories: Prevention, Appraisal, Internal Failure, costs due to Supplier Failure, and External Failure (Escapes).[21] These five categories were encoded by two digit dash numbers on the shop order to create 32 different quality classifications. This system provided more detail than the current system and is planned to be used as a proxy to an ABC system.

Phase 1.4 - Identify current and needed skills:

The MPVR program provided the focus for the company as it identified its workforce competency and skill requirements. This program put a premium on the use of statistical methods for process improvement. Accordingly, the company sought to exploit current expertise and expanded this expertise in its workforce.

Phase 1.5 - Fill skill gaps with corporate wide training:

The company developed an internal training program that outlined specific mechanic qualifications. In order to attain internal mechanic certification, all new assembly line mechanics were required to receive 240 hours of training in the following areas: Basic Skills, Basic Math & Precision Measuring Tools, Blue Prints, Process Specifications, Hole Preparation & Countersink, Fasteners, Trim & Drill Fundamentals, Sealant, Parts Handling, Foreign Object Elimination, Safety and Hazardous Materials, and the company data management systems. Mechanics using SPC were given eight hours of training leading to an SPC certification. Since the introduction of this program in 1993, most of the newer program mechanics have graduated.

[21] Prevention and appraisal costs currently represent one-third of Cost of Quality.

Phase 1.7 - Assess technology impacts:

One of the projects that a process improvement team used for improving assembly operations in the newer program was the development of an automated drilling gantry. This piece of equipment was developed by adding rails to an assembly jig which was mounted on a gantry. Relative positioning was determined by the application of a touch probe and a GE Fanuc CNC controller. This adapted technology reduced part-to-part variability by locating holes relative to datums on each specific part and removing operator variability from the drilling operation. The improvement team also simplified assembly tooling designs by utilizing commercially available off-the-shelf components and lighter materials.

Phase 1.8 Establish linkages with supplier and customer base:

Due to the company's increased reliance on external suppliers, it was consolidating its supplier base to a more manageable level. They reduced the number of machined parts suppliers from 300 to 65 and the overall number of suppliers from 1000 to 300.

To support the consolidation process, the company established Integrated Supplier Management Teams (ISMT). ISMT was implemented with suppliers focusing initially on general procurement materials. The ISMT was composed of a buyer, manufacturing engineer, quality assurance representative and a supplier representative. ISMT improved all aspects of product management communication.

At the time of the case study, 27 percent of its suppliers were classified as "Key Plan Suppliers". The pre-qualifications of a Key Plan Supplier include the following delivery performance measurements: 99 percent fill rate, 98 percent on-time, 95 percent documentation accuracy. Suppliers that satisfy the Key Plan Supplier requirements received: payment on receipt, first choice in new product sourcing, and the opportunity to receive sole source contracts.

The outsourcing of fabrication subsequently increased the number of issued purchase orders from 4,000 to 18,000 while the number of materials management personnel decreased. In an effort to improve the procurement process, the company initiated a reengineering program focused on streamlining the auto-requisition and auto-change order processes. One of the objectives of this project was to reduce ordering lead-times as well as the variability surrounding ordering lead-times.

The company has worked to achieve the highest rating with it customer as well. The customer has three levels of supplier certifications (Gold, Silver and Bronze) that imply various relationships. The evaluations subject suppliers to an analysis of the following weighted performance certification areas: management involvement, process focus, SPC implementation and documentation, employee involvement, capability, process documentation, criteria for selecting key process, selection of process characteristics. The company received bronze supplier certifications for SPC in 1993, for business management in 1994, for cost and performance in 1994.

The company's customer requirements regarding processes and systems, including the implementation of SPC, increased significantly over the past five years and particularly with the newer program. In addition, management acknowledged that the receipt of future contracts become increasingly dependent on past performance.

Stage Four

Implementing Phase 4 - Process Improvement (concurrent implementation)

Phase 4.1 Improve process and operations predictability:

In airframe assembly, the splice operation tended to be the operation most vulnerable to process and/or product variation. In the newer line, 8 key characteristics at the splice interface assisted in the improving the splice operation. The splice operation time was reduced significantly from four days on the older line shipset #1 to one-half day on the newer line shipset #1 due to reduced product variability, increased coordination and an improved design incorporating lessons learned from the older program.

Another example of the effects of reduced product variability was the assembly of the vertical stabilizer to the fuselage. On the older program, the vertical stabilizers were hand-crafted to match each unique fuselage. On the newer program, variability between the vertical stabilizer and the fuselage was reduced by better positioning the pieces within tolerances and the simultaneous drilling of the mating surfaces. The company has experienced only 0.02 percent defects in this operation on the newer line and gained considerable service benefits as the mating surfaces are now completely interchangeable with other fuselages.

Throughout the newer program, the customer attempted to make sure that everyone utilized the same language by introducing a concept called “geometric dimensioning and tolerancing” (GD&T). GD&T required designers to define a part based on functional datums or the part’s functional surfaces. It is a standardized language that helps assembly mechanics and inspectors interpret engineering notes in the same way. With a common language, engineers used GD&T to explain how pieces fit together, where holes should go, and what the important features of the part are. Consequently, assemblers were less likely to misunderstand the designers’ intentions.

The customer also helped lay the groundwork in minimizing tolerance build-ups, which can prevent the smooth assembly and fit of some pieces. The customer started a variability reduction program that identified mating surfaces key to fitting up the airplane. Product centers were instructed to machine those surfaces to nominal tolerances so that there would be no step increment between the two pieces.

As mentioned earlier, the Manufacturing Process Variability Reduction (MPVR) program was the cornerstone of the company’s lean transition. Top company leadership was directly involved in the executive steering group which met quarterly to review the implementation. The objective of the MPVR program was to reduce process variability throughout the organization. This program was coordinated across Process Improvement, Definition and Documentation (e.g., product IPTs), Support Activities (e.g., process IPTs, SPC specialists, computer systems), the Transfer Inspection Verification Initiative and External Supplier ISMT.

This coordinated effort clearly defined the responsibilities for the various parties involved. The MPVR master plan was developed in 1992 and piloted in 1993. Full-scale implementation of this program began in 1994.

The company embraced the philosophy that successful MPVR/SPC required the following elements: 1) executive management leadership and support, 2) team approach, 3) education of employees at all levels, 4) emphasis on continuous improvement, 5) and a mechanism for recognizing success.

Phase 4.2 Improve process quality:

The company developed an initiative which described the process, defined process capability and gage R&R, and presented the SPC user interface. It also implemented variable SPC data collection on approximately 3,500 out of a planned 18,000 close tolerance holes and approximately 5,000 out of a planned 7,500 countersinks on the assembly line with SPC software, and associated data acquisition equipment. This data was analyzed by both manufacturing and quality personnel to provide mechanics with feedback and to track the process capability (Cpk) of various operations. The company used pareto analysis techniques to help focus the Cpk improvement efforts. In 80 percent of the close tolerance holes, the company has achieved Cpk values greater than 1.0 and 75 percent of the close tolerance holes had Cpk values greater than 1.33. In 32 percent of the countersink operations, the company achieved Cpk values greater than 1.0 and 11 percent had Cpk values greater than 1.33.

In an assembly operation, a mechanic's work standards included some preprocessing measurement before completing the operation. In other words, the mechanic typically pre-drilled three holes and gaged them in order to ensure that process was within specification before attempting to complete all of the hole-drilling requirements for that operation. Holes are gauged throughout the operation to a predetermined sampling plan based on the quantity of holes being drilled and historical Cpk data. When a mechanic observed a deviation, he was responsible for identifying and classifying the cause of the deviation on a comprehensive checklist used by manufacturing to investigate process variation.

The company also developed flexible tooling through a technology project whose objective was to reduce operator variability in difficult drilling operations. The tooling was not only successful in reducing process variability but it also increased process throughput speed.

Appendix B: Case Study Number Two

Introduction

This case study is of a major defense and commercial aircraft company in the airframe sector of the Lean Aircraft Initiative. The subject of this case study was a modernization program that was implemented to improve the flow of fabricated parts through the production process. This case study was performed to compare the implementation process used in the modernization program to the hypothesized Lean Implementation Model.

This case was chosen for study because if was the newest example within the LAI that had started a lean transition. We thought that understanding the change process and early decisions would be valuable to the research effort even though the transformation has not been completed.

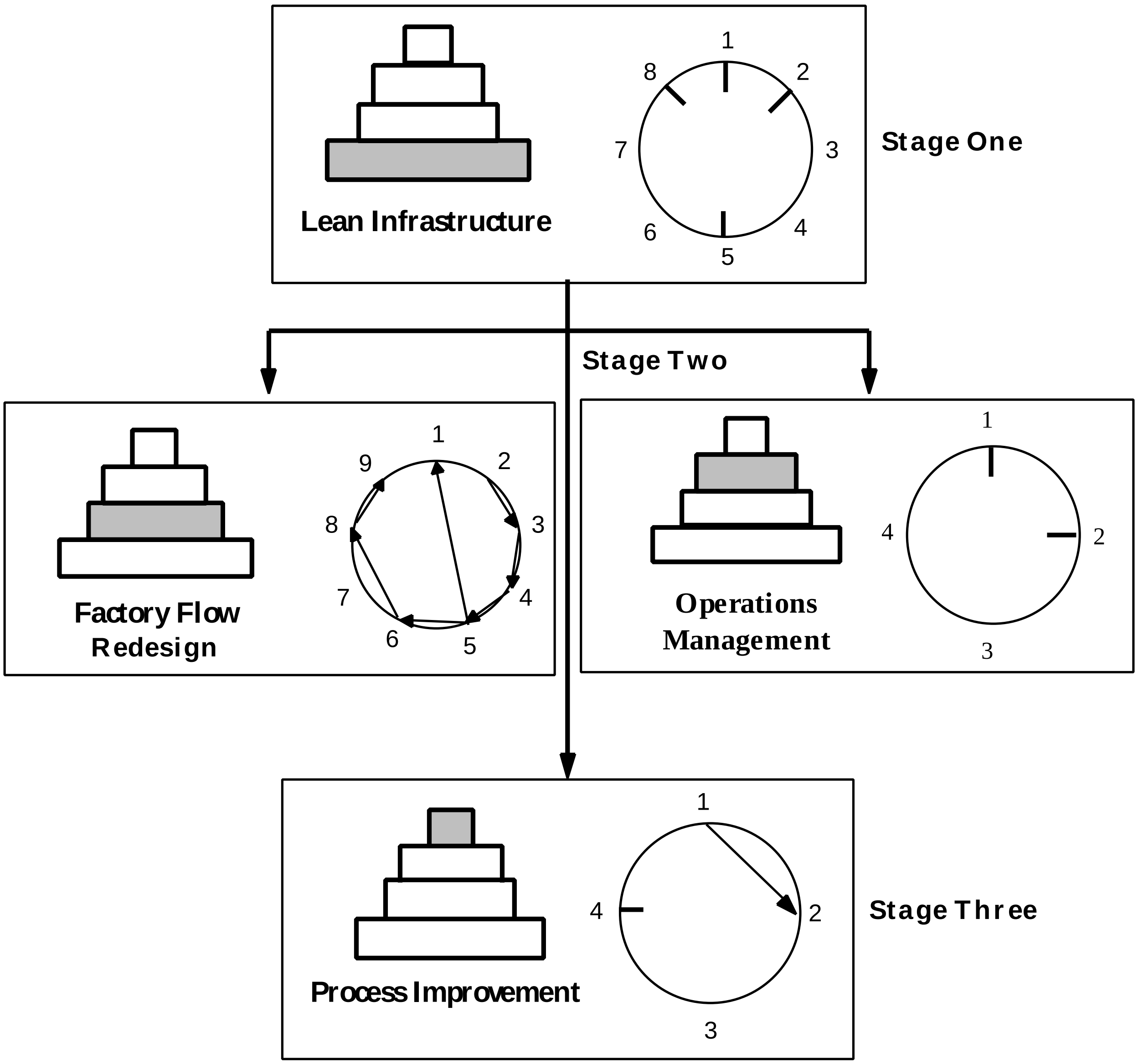
Total Transition Implementation Sequence

The following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix B Figure 1 shows the process or sequence followed. Each box or level in the diagram represents a stage of lean implementation.

The first stage was characterized as lean infrastructure building. This was started before the modernization program with a Total Quality Management program. This program had limited success but did focus on employee training and addressed the cultural changes necessary in the models lean infrastructure phase. Later in this stage benchmarking activities occurred which became the impetus to continue the lean transition and to focus their next efforts onto a factory modernization program.

In the second stage of the transition, the company addressed factory flow redesign and operation management development ideas simultaneously. At the time of our case study this stage had just been completed. We found that the factory flow redesign state was characterized by a rapid change from functional manufacturing processing areas to manufacturing cells. Unique methods were used to determine the product grouping necessary to establish efficient cells. They executed the changes with teams of engineers and managers using shop floor operators to fine tune the layouts within the cells. Concurrently they started employee training and the reallocation of support resources.

In the final stage of this transition we witnessed a renewed effort to understand their process capabilities and to improve their process quality. We also saw technology employed to increase process speed.



Appendix B Figure 1: Case Study Two Implementation Sequence

Stage One

Implementation of Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy:

The implementation of the company's manufacturing strategy, which was based on Total Quality Management (TQM), evolved as the company learned more about TQM and incorporated the human element more fully into the program. One of management's objectives was to use their TQM program to breakdown the stovepipe mentality that existed in the past.

The company's TQM hierarchy was composed of three levels. The first level was the steering committee which included the Chairman's staff. The second level was the team council which met weekly to set and review policies. It was composed of vice president appointees plus three union representatives. The third level was the Issue Management Board (IMB) which identified problems, selected teams to address problems and prioritized issues and assignments. The IMB was comprised of management and union representation at a department level.

The implementation of TQM evolved from an unsuccessful management edict into an environment that supported changes in the way work was done. Furthermore, it appeared that the company's employees were actively engaged in the cultural transformation occurring in their workplace. Since the TQM process was in its infancy stage, they were still working through a number of problems.

- First, TQM was originally regarded as a "popular management science mechanism" that would help them achieve a 30 percent reduction in manufacturing costs. This objective was strongly resisted by the union and employees because the cost reduction terminology implied hourly and possibly salary layoffs. Consequently, the company was unsuccessful in its first attempt at implementing TQM. The key lesson learned by management from this experience was that TQM required active employee participation and employees can not be coerced into participation. Employees must be motivated in a similar manner as management in order to successfully implement this type of program across the entire organization.
- Second, the company made a large investment in employee training up-front before management had developed a clear definition of the TQM process and or how it should operate. This problem was important because it illustrated the manifestation of a less than optimal implementation sequence. It was very important that an organization develop a thoughtful and clearly articulated manufacturing strategy prior to providing employees with skills that they will not be able to use within a short-term horizon.
- A third problem that was limiting the company's ability to receive maximum benefits from TQM was the inconsistency of employee incentives with expected behavior. Group managers supported TQM but were not actively engaged in it because their incentives did not directly motivate them to support it. Supervisors were not motivated to release operators from daily functions in order to work on team projects.
- The fourth major implementation hurdle limiting the company's potential was the lack of resources to implement change. The company's engineering personnel were preoccupied with the plant reorganization and modernization effort and were therefore not readily available to facilitate and/or support shop-floor employee problem-solving and solution execution. Another restriction faced by shop-floor employees who had previously undergone problem-solving exercises was the inability to implement change due to financial constraints. One of the key lessons learned from successful *Kaizen* events was that employee motivation and participation was directly related to the level of impact their newly empowered positions would allow. In other words, if employee-developed process improvement changes are not implemented, the participants will probably view the process as wasteful in itself and will be less inclined to participate in future management-sponsored TQM events.

In order to mitigate some of the current problems with TQM, Quality Assurance (QA) proposed many changes. One of the more significant changes was to restructure the IMB. The plan was to engage vice presidents more actively in the TQM process by delegating the IMB chairman's responsibilities to the vice presidents in the core businesses. This represented a significant reorganization of the company's management structure. Each vice president focused on performing a critical business activity that would support all product lines. The list of proposed activities included: product development, product sales, product manufacturing, customer support and company support. The focus was on the company's day-to-day operating activities. The IMB met on a monthly basis and all IMB chairs were required to report to the President's Steering Committee on a quarterly basis. These changes were planned to model the business after Deming's "plan, do, check, act" philosophy.

Phase 1.2 Perform benchmarking:

The company conducted a number of benchmarking activities in order to learn about lean manufacturing transitions that had taken place in other companies. These trips and consulting engagements were focused on strategic planning, information systems and factory flow redesign. As part of the company's factory flow redesign efforts, industrial and manufacturing engineering visited a number of manufacturing facilities that had undergone similar plant reorganizations. The knowledge gathered on these trips, combined with their consultants' experience and advice, formed the basic factory flow redesign process that was used in cellularizing their manufacturing processes. Benchmarking and plant visits expanded their knowledge base which they leveraged in the planning stages of their factory flow redesign.

Phase 1.5 Fill skill gaps with corporate wide training:

The corporate-wide training had been limited to TQM training. The company made a large investment in employee TQM training as the first step in the introduction of this concept. Other skill training was more decentralized. We gave credit for the implementation of this step but must acknowledge that it was not a strong implementation.

Phase 1.8 Establish linkages with supplier and customer base:

The company outsourced approximately 20 percent of its products. Consequently, the company's supplier management program has not historically played an important role in the overall business. Recent contract awards have, however, initiated increased make-buy tradeoff analysis activities and the level of outsourcing is rising.

The organization's Factory Flow Redesign efforts unveiled products that have unique process routings. The company's benchmarking exposure to John Deere made them reconsider the value of producing a product that doesn't share common processes with other products and/or can not be grouped with other products or processes. The organization adopted the philosophy that if a product doesn't "fit" with any of the organization's product groupings or process flows, then it should probably be outsourced.

Spare parts are also being increasingly outsourced because of the disruption they may cause in the entire manufacturing system. Since spare part demand is highly volatile and unpredictable, the actual cost of producing spare parts which includes disruption and inefficiencies in the current system may often be greater than the standard costing system estimate. Therefore, the profitability of the entire system may be greater if manufacturing of spare parts is outsourced in order to minimize disruptions due to spare part orders.

Stage Two

Implementing Phase 2 - Factory Flow Redesign (concurrent implementation)

The facility we visited performed both metal cutting and sheet metal processing. The pre-transition factory floor layout philosophy squeezed similar pieces of equipment into areas where there was empty floor space. The linkages between departments were not considered during layout development. Consequently, the various manufacturing departments were not coordinated to optimize process or part flow paths. For example, the vertical milling machine department in the pre-transition layout was located amongst hydroform and chemical processing equipment and was not located near other machining operations like drilling, deburring, etc. The process flow paths for a particular part that required vertical milling often looked like spaghetti laid on top of a factory layout.

In 1994, the company began a major modernization program whose objectives were to reduce the environmental hazards associated with their chemical processing operations. Increasingly stringent EPA regulations forced the company to scrap some of their old equipment, purchase new equipment and modify some of their operating practices. The modernization of their processing equipment provided the company with the opportunity to perform a major transformation on the entire facility.

The investment capital and moving expenses associated with the large-scale layout changes were justified on economic returns except for the new chrome plating and chemical treatment equipment costs which were justified by EPA requirements. The company's overall cost reduction target for the project was 30 percent and its inventory reduction objective was 50 percent.

The Factory Floor Redesign process at this company can be summarized by the following major steps:

1) Group parts by creating an identifier for each flow path,
2) Incorporate realization factor into process families,
3) Prioritize part number families by annual resource requirements (i.e., the greatest annual processing requirements received the highest priority),
4) Solicit operator input for optimal internal cell design,
5) Repeat process using iterative simulation analysis with various operating assumptions.

Phase 2.2 Group products into families:

The machine shop departments process over 6,000 different part numbers annually on 140 machines. Most of the equipment in the machining areas could be moved fairly easily. Prior to the factory floor redesign project, the machining departments were located in three different areas of the plant. Since the machining departments were not located in close proximity to each other, machined parts often traveled large distances and suffered significant delays in processing.

The Sheet Metal departments perform many varied operations on 160 machines. Sheet metal fabrication produced approximately 30,000 different part numbers annually in mostly low quantities. An important characteristic that identified this area was the term "monuments". "Monuments" were large pieces of equipment, such as hydroform presses, that are difficult to incorporate in layout design changes because they are prohibitively expensive to relocate.

Since the company manufactured a large number of different parts in a large variety of part geometries, they could not establish significant part families that would assist them in developing manufacturing cells. Instead, the company's manufacturing cell design was based on grouping parts that have similar product routings. The machine shop was originally laid out by grouping similar processes together (i.e., vertical milling, lathes, grinders, etc.).

Unfortunately the various machining cells appeared to be randomly dispersed throughout the plant and products often traveled significant distances and required long lead-times between operations. In the new layout design, engineering analyzed process routings and attempted to group machinery in cells in order to optimize the different product flow paths linked across manufacturing cells. They also integrated debur processing operations into each cell thereby eliminating the requirement of transferring WIP to a separate debur cell. In essence, they defined operations in cells relative to products with similar processing requirements, e.g., parts do not necessarily require similar geometries in order to be processed in the same cell. Additionally, they have also minimized part travel distances by locating cells that have parts with similar processing requirements adjacent to or near each other.

The company could not, however, adopt a greenfield approach. Many of its existing sheet metal processes could not be moved and consequently constrained the overall plant layout. These "monuments" included hydroform presses and many of the plants chemical processing operations. For example, chemical milling utilized hazardous materials that were difficult to collocate with other types of manufacturing operations for environmental reasons.

Part Number	Operation	Department	Subsection	Work Center
XXX	10	1	011	115
XXX	20	101	013	219
XXX	30	801	014	201
XXX	**Total**	**903**	**038**	**535**

Appendix B Table 1: Creation of Process Flow Identifier for Part Number XXX

In the grouping process, an identifier for each part was created based on department number, subsection number and work center number. Each unique resource at the factory was defined as a work center in a department. The above table illustrates how the identifier was generated by summing each of the descriptive fields and concatenating this series of sums into one number. In Appendix B Table 1 above, the identifier for part number XXX is 903038535. Using this methodology, 1,139 families and 13,000 flow paths were identified in Plant #1.[22] This initial process ignored the sequence of operations and the occurrence of multiple operations on the same machine.

Phase 2.3 Standardize processes:

Once this process was completed for each product flow, all of the identifiers were compared against one another for duplication. Duplicate identifiers were grouped together to create a process routing family. These groupings were further optimized by comparing additional fields: number of operations and hours of processing required per year. In Appendix B Table 2, four different part numbers are sorted by pareto analysis by the number of hours of processing required per year. In this example, part numbers XXW, XXX and XXZ would be grouped together in the same process family called Hydroform. By focusing on the part numbers that require significant annual operating resources (approximately 20 percent of all part numbers), the company maximized the potential benefits (80 percent of required resources) of cellularization.

Family	P/N	Dept.	Subsect.	Work Center	No. of Ops.	Hrs/Yr.
Hydroform	XXW	903	038	535	5	250
Hydroform	XXX	903	038	535	6	130
Vertical CNC	XXY	813	58	200	8	95
Hydroform	XXZ	903	038	535	6	65

Appendix B Table 2: Analysis of Resource Requirements for Process Identifiers

Phase 2.4 Design process layout and simulate flow:

22 A flowpath is a unique method of processing a part. There are 13,000 unique ways of processing parts in both the sheet metal and machining areas.

The company analyzed the different families of parts based on which resources were required. They then developed cells around the family that required the greatest number of hours. The company did not model their redesigned cells with software simulation tools. They did, however, develop a metric to measure the degree of cellularization in each cell. The performance metric measures the percentage of parts within a family that are completed within that cell. The company uses pareto analysis techniques based on loading factors to select the family with the highest percentage as an optimal cell design and then incorporates other families into that cell. The goal was to achieve at least 90 percent cellularization in a cell design. This implies that 90 percent of the parts that flow through a cell are completed in that cell.

In sheet metal fabrication, part numbers that were processed by monuments were analyzed to identify the other operations that were performed on those parts. The monuments became the key operations within the model cells and supporting processing operations were subsequently placed around the monuments to complete the cell design. Models of cells were developed to determine the cellularization percentages. The company measured the degree of cellularization in sheet metal fabrication cells as the percentage of parts within a family that "touch" a monument within that cell. Capital planning improvements were then linked to these models. This process was referred to as the "common sense about monuments" approach to cellularization.

Phase 2.5 Optimize factory flow and cell linkages:

Each proposed plan was developed by a team of engineers and managers and was further rationalized by shop-floor operators. Initially, operators were engaged in cell redesigns at an earlier stage in the process, but this was counter-productive because the operator-populated teams became bogged down with numerous detail tasks. Even though some of these tasks, which included the selection of the department microwave oven and lunch cooler locations, were important to the operators, they were not directly salient to optimizing process flow. The company realized that this outcome may have been avoided if the team's objective and timeframe had been more clearly outlined. This would have allowed team members to stay focused on their assignments.

Subsequently, engineering and management designed the cells and operators helped determine the best part flow within the cell. Unfortunately, some of the other layout details, such as tool crib set-up and incoming/outgoing material locations, have not been addressed by the master plan due to limited engineering resources.

Another area of concern with respect to the company's cellularization process was the learning from one cell was difficult to incorporate in the design of other cells. Since work cells are being developed and implemented almost simultaneously, it was difficult to analyze the learning from the first cell in order to optimize later cell designs. The hypothesized model recommends the implementation of pilot cells in order to maximize learning from them before optimizing the entire factory operation. It was also very difficult to redesign the entire factory flow while attempting to satisfy normal production requirements.

An example of a redesigned cell is the Hydroform cell. This cell processed 676,981 total parts under 7,196 different part numbers annually. Approximately, 29 percent of all sheet metal operations performed in the facility are assigned to this cell.[23] The company measures successful cell definition and grouping by measuring the percentage of required work completed on a product in a cell. In the Hydroform cell, 90 percent of all operations required to be completed on any product routed through this cell was completed within the cell.

Phase 2.1 Distribute information:

In the process of defining the new factory layout and establishing cell linkages, it became clear that the teams had to be given the information necessary to focus on the optimizing of the cell. Without the guidance of this information, the teams focused only on areas of interest to its members.

Phase 2.6 Redefine and redeploy work tasks:

Work tasks were defined using the processing hours required as the guide as explained earlier. With this information the cells were laid out and work was started under the new arrangement. Although the work tasks have been changed, the company has experienced some significant challenges in keeping up with the changes to the work instructions.

Phase 2.8 Construct cells through *kaizen* events:

This company developed the product grouping information and the rough layout necessary to accomplish the new layout. It then solicited operator input for optimizing the internal cell design. This process was accomplished in teams and the process was similar to *Kaizen* events.

Phase 2.9 Make product flow visible within the cell:

This was accomplished by changing some of the transportation between operations from fork lifts to operators.

Implementing Phase 3 - Operations Management Development (concurrent implementation)

Phase 3.1 Cross-train workers and realign incentives:

[23] The remaining 71% of sheet metal operations do not require processing by the Hydroform presses and are therefore processed in other cells.

At the time of the case study, shop-floor employees were segregated by a number of different pay grades. High pay grade employees can be assigned to perform low pay grade tasks, but low pay grade employees were contractually restricted from performing high pay grade employee tasks. The company was also attempting to expand the responsibilities of workers by assigning multiple work centers (machines) to each operator. In addition to these changes, the company was currently in the process of transferring Quality Assurance (QA) responsibilities from the functional QA department to the shop floor production departments. In order for QA to certify a process, the operators were required to take a 12 hour SPC training class and then pass a written test. Inspectors and engineers were required to take a 24 hour SPC course. It was too early in the process to measure the relative success or failure of this program.

Each cell used an hourly planner or "crew chief" to schedule machinery based on the daily production plan and on interactions with management and other expediters. Each cell also used a set-up person who assists in performing external setup elements, such as the procurement of tooling and other set-up materials. Most operators were expected to preset cutting tools and set-up their individual jobs. Target flow times for products entering a cell were three days or less. Material flow was sometimes interrupted by expediters. For example, running set-ups were only broken down (interrupted) by "hot" parts once per week in the vertical CNC cell.

An example of the impact of employee cross training was witnessed in the improvements in tooling pre-sets. Experienced machine tool operators were reassigned to the tool room displacing the employees who previously performed these tasks. Since the new tool room personnel were the previous customers of the tool room, they were able to directly utilize their machine tool experience and translate it into improved tooling pre-sets.

The training process at the company was uncoordinated and decentralized. The human resources department was only responsible for providing basic technical and supervisory management training; this level of training was similar to that proposed in the Lean Infrastructure section. Any supplementary training that may be required to support any of the lean transition phases, such as topics in the areas of cellular manufacturing, TQM, statistical methods, communications, problem-solving, etc. must be coordinated and provided by the sponsoring functional groups.

In the assembly area, unskilled operators received some basic sheet metal training but rely primarily on on-the-job training. Since work instructions in these areas are regarded as "tribal knowledge", it is unclear how much cross-functional skill development has been achieved and whether the company has received any increased employee flexibility benefits in this area.

Phase 3.2 Reallocate support resources:

Two Manufacturing Engineering and two Quality Assurance personnel supported the sheet metal and machining areas. The increased collocation of CNC programmers, tooling engineers, and tool planners within the fabrication plant enabled manufacturing to assume greater control over these areas. This is an important change because one of the biggest problems faced was reducing tool shortages. By controlling the areas with the greatest influence over tool shortages, production should be able to reduce delays due to tool shortages.

The company implemented autonomous maintenance practices in some chemical processing areas. In the Chemical and Painting cells, operators routinely change filters, check tanks and wash down scrubbers. Since the operators began performing these tasks, the supervisor in the area has noticed increased up-time performance on this equipment. In this same area, the operators have also been actively involved in the design of racks, baskets and other tooling. Post-layout change processing capacity for this cell has increased by 50 percent with no additional operators.

Stage Three

Implementing Phase 4 - Process Improvement

Phase 4.1 Improve process and operations predictability:

The company focused considerable efforts on its variability reduction program. The basis for this program was both supplier control and statistical process control. Through the use of process capability studies based on SPC data collection, QA assisted industrial engineering to both simulate and improve manufacturing cell designs. Furthermore, as the company's shop floor employees become more involved, they were developing methods of reprocessing products more efficiently. This step, not only reduced set-up variation, but it also improved overall throughput.

The Quality Assurance department at the company administered most product and process quality functions. QA initiated the VR/SPC program plan which includes the following three parts:

1. A Material Field Quality Engineer (MFQE) was assigned to each supplier in order to ensure that the supplier had a quality system in place and that the supplier provided statistical quality data with each lot. This process helped control process inputs.
2. The organization studied underwent an internal transition from a product-focus orientation to a process-focus orientation based on their 15 step approach. QA had 300 process capability studies underway in this area. These studies were based on individual asset numbers (i.e., the equipment used in the process). Each work order docket (that traveled with the lot of materials) included a machine capability study sheet that the operator was required to fill-in with measured data about the process. These study sheets formed the database for QA's machine capability studies. 230 out of 656 process capability studies were completed in Plant #1 so far.[24]
3. Responsibility for the identification of key characteristics will be delegated to cross-functional assembly teams in the future. Key characteristics were determined by product engineering during the product design phase. The delegation of this responsibility to shop

[24] In some instances, QA used first pass yield data as a surrogate for Cpk data when statistical variable data was not available.

floor assembly teams was expected to assist assembly mechanics in consistently performing high-quality assembly functions.

At the anticipated completion of the VR/SPC program in 1998, there will be 92 teams operating at the company. Of which, 70 will be active VR/SPC teams, 12 teams will be special process teams and 10 will be MFQE teams facilitating supplier component improvements and JIT deliveries.

Phase 4.2 Improve process quality:

The company was utilizing Variation Simulation Analysis (VSA) to perform Monte Carlo simulations on tolerance stack-ups. VSA is a software package that accepts a variety of tooling, process and assembly information, and then simulates the assembly operation. The output provides the user with statistical information on the specific assembly characteristics of the part. Any dimensions identified by VSA as causing unacceptable assembly problems due to large tolerances were then defined by manufacturing as “key characteristics”. This activity, along with machine capability studies, assisted both product engineers to improve their designs and manufacturing engineers to determine process routings and cell design.

With the efforts of the VR/SPC program and the VSA, the company improved its quality levels sufficiently to boast improved quality by being one of the few FAA-approved airframe manufacturers to utilize statistical sampling inspection methods.

Phase 4.4 Increase process speed:

Through its modernization program, the company also purchased new high speed milling machines. This equipment will increase process speed and will require less floor space among other advantages than the equivalent processing capability of traditional milling machines. Even though this step appears out of sequence from the hypothesized model, it illustrates how the timing of the company’s plant-wide Factory Flow Redesign phase has impacted the decision to implement activities in other phases of the model.

Since process speed was being achieved only on a single program and not systematically, it was not judged to be directly associated with the other process improvement implementation efforts. However, it could not be ignored. Therefore, this phase step is recognized with a tick mark and not a sequence arrow.

Appendix C: Case Study Number Three

Introduction

This case study is of a major defense company in the electronic sector of the Lean Aircraft Initiative. The product which is the focus of this case study is produced in competitive lot production basis with one other competing contractor. This case study focused on the production improvements that were realized over a four year period as the company sought to outperform the competition.

The competitive bidding for the products in this company has driven cost reductions. These pressures have instigated some lean transitions in this company. This case study was chosen because it captured a lean transition that was instigated by market forces. The application of technology and the outsourcing of fabrication have played a significant role in this program. Outsourcing has led the program office to invest heavily in supplier development and certification programs. After assessing work methodologies in other organizations, the program management began investing in people systems and team development to nurture a culture that supported interaction between product and functional groups.

Total Transition Implementation Sequence

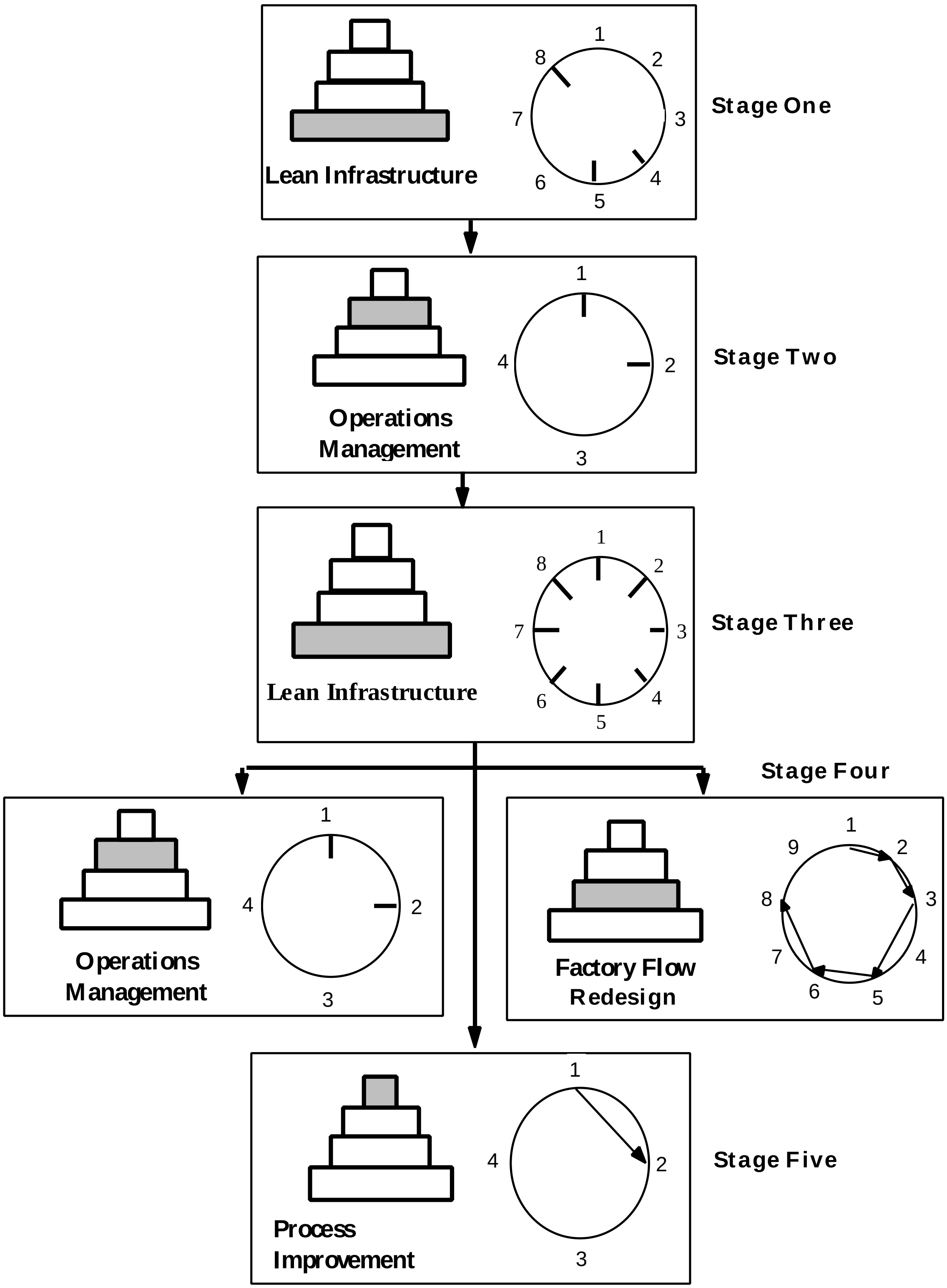
The following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix C Figure 1 shows the process or sequence followed. Each box or level in the diagram represents a stage of lean implementation.

In the first stage of this lean transition, the whole company started lean infrastructure changes with emphasis on information technology, acquiring the needed skills, employee training and linkages with their suppliers. This effort focused on Self-Directed Work Teams (SDWTs) but was not universally successful.

The second stage's focus on operations management followed closely behind the first stage.   Associated with SDWTs, the company initiated a pay-for-knowledge program as it transitioned away from functional organizations. These efforts ran into problems however, which forced a refocus on their transition.

The third stage of their lean transition focused on applying lessons learned from their previous efforts and reallocating employee responsibilities. Benchmarking how others had realigned their workforce led to the application of all but one of the elements of the lean infrastructure phase of the hypothesized lean implementation model. In this round of lean infrastructure development, the company concentrated more on the humanistic side of the implementation.

After reemphasizing the lean infrastructure efforts, the f orth stage capitalized on this foundation to simultaneously focus on operations management and factory flow changes. In particular, a new round of worker training and support reallocation through the implementation of IPTs occurred as the teams focused on streamlining the flow of product and establishing assembly cells.



Appendix C Figure 1: Case Study Number Three Implementation Sequence

Stage One

Implementation of Phase 1 - Lean Infrastructure

Phase 1.4 Identify current and needed skills:

The company workforce was composed of two major demographic units segregated by age groups. Since the younger workforce was educated more recently than the older group, retention of math and comprehension skills is greater among the younger workforce. Therefore, the younger employees had fresher quantitative capabilities and were better able to apply statistical methods to problem-solving. The company needed to raise the level of understanding of these skills with the older workforce as well.

Phase 1.5 Fill skill gaps with corporate wide training

The older group was initially intimidated by the knowledge gap because it reduced the traditional importance associated with older employee experience and clearly identified this group's inability to work in a modern manufacturing environment. The company recognized this problem and subsequently co-developed courses with the local community college, as part of its Career Enrichment Program (CEP), that enabled the older employees to take refresher courses in high school mathematics in a more supportive environment.

As a result, overall literacy improved significantly with the introduction of basic communications and mathematics courses at the community college. This increase in skills enabled the employees to do more complex tasks requiring statistical tools such as SPC and other problem problem-solving methodologies.

Phase 1.8 Establish Linkages with Supplier and Customer Base:

Each unit was assembled from more than 5,000 parts of which a large number are outsourced. Therefore, supplier management played a critical role in the manufacture of this product. The Project Engineer (PE) on each IPT coordinated both internal and external supplier activities. The PE chose suppliers by completing a "readiness plan" which was used to analyze a potential supplier's capability. The company also provided SPC training for its suppliers in the same format that it provided to its own employees. In this way, the company created a common knowledge base and language to address problems.
Delivery frequencies were driven by product unit costs. The program's direction was to increase the number of purchased parts delivered directly to dispatch which is one step prior to point-of-use. Total inventory was estimated to turn twice per year. The program office was

also responsible for carrying its own inventory and its profitability was negatively impacted by excessive inventory.

Many of the program's suppliers were large-scale commercial suppliers that preferred to support large-scale commercial customers (e.g., Packard Bell) due to the commercial customer's larger volumes and lower quality and engineering requirements. Commercial orders may be as large as 2 million units while a typical defense order may only be 500 units.

The drive to use commercially available products, under the DoD Acquisition Reform program, has been difficult to achieve. Electronic components in particular, that have high reliability requirements demanded intensive screening and certification before successful application. This fact combined with its low buyer power made the company commercial supplier programs difficult to manage.

Stage Two

Implementation of Phase 3 - Operations Management Development

Phase 3.1 Cross-train Workers and Realign Incentives:

The company implemented a Career Enrichment Program (CEP) which was a "pay-for-knowledge" program. CEP was established in 1987 in a joint management-union effort to give workers greater job enrichment opportunities and provided the company with a more skilled, flexible workforce. Employees were eligible to qualify for additional job units and pay increases by successfully fulfilling predefined educational requirements.
The number of job categories decreased from 146 to 60 in five functional job families. Within each family, the units were arranged in levels of increasing knowledge, skills and abilities, with movement to higher, better-paid levels dependent on successful completion of company-funded courses offered at the local community college. Employees must successfully pass tests in order to receive credit.

Employees expanded their skills both vertically and horizontally across the unit levels. This arrangement gave them greater flexibility and allowed them to move around the company wherever their skills were needed. However, once they moved to a higher level, their pay remained at the same higher level, regardless of what task they were performing. The company valued worker flexibility because it enhanced worker productivity. Flexible workers allowed the company to optimize the variability in its operation.

The rest of the company was transitioning from a functionally based organization to a process team based organization structure. Incentive programs and career path planning were modified to support this transition.

The company initiated a comprehensive award program that recognized and rewarded contributions that have enhanced the company's values and goals. In this program, there were three levels of cash and non-cash awards for both teams and individuals. The variety of awards was designed to provide maximum flexibility in recognizing achievement.

3.2 Reallocate Support Resources:

Support resources were reallocated with the development of IPTs. However, the incentive system that motivates support personnel operating out of enterprise functional groups was not realigned to fully support the program's operating philosophy. Furthermore, since the program's operating philosophy has not been adopted throughout the company, barriers separating centralized functional "homerooms" and the program still exist.

Homerooms are the centralized functional departments which provide support services, such as product engineering, maintenance and material control, to the production facilities. Support resources are centralized throughout the company. The previous and current operating philosophy is to allocate resources to the various program offices on an as-needed basis.

Stage Three

Implementation of Phase 1 - Lean Infrastructure

Phase 1.1 Identify Business Issues/Goals and Develop a Strategy:

The program mission statement focused on continuous measurable improvement (CMI) as it sequentially executed the following objectives: 1) create a fulfilling work environment, 2) produce quality products/services, 3) exceed customer expectations, 4) increase market share, 5) increase financial returns.

The product's inherently flexible design expanded the number of applications that the program could fulfill. Even though the product was originally designed for a specific mission, another customer recently expressed a strong interest in purchasing the product for a different mission. The company innovation in the hardware/software navigation module enabled the realization of this product application.

Leadership in this program also played an important role in determining the level of success the enterprise achieved in its lean transitions. Previous program managers implemented change in other parts of the company built largely on the lessons learned from this program. Company leadership enabled change by: providing resources, breaking down barriers and simply by walking the talk.

Phase 1.2 Perform Benchmarking:

Before an IPT was implemented, the program operations management team visited a number of companies that had successfully redefined employee responsibilities and job functions.[25] These educational visits increased management's awareness of the potential improvements that could be achieved by changing their work methodology. If the company did not benchmark their human resource management system against other organizations (especially those outside of their industry), the company would not have made as many significant human resource policy changes and consequently would not have received as many benefits.

Phase 1.3 Develop an Information Technology Hardware and Software Strategy:

Badge readers were implemented to help control product flow. Based on the part chosen for work, a set of operator instructions were displayed to facilitate the assembly of this part.

Phase 1.4 Identify current and needed skills:

The company had attempted to implement self directed work teams but had not had the results it had expected. The shortcomings of this implementation were attributed to some lean infrastructure shortcomings. The program interviewed its members extensively and identified that work styles were important to success. On the second try, work style preference surveys were given to members, suppliers and customers to identify current styles and the need for team realignment.

Phase 1.5 Fill skill gaps with corporate wide training

The CEP with the local community college continued during this stage.

Phase 1.6 Breakdown Stovepipe Mentality:

The program office clearly defined the operating environment that it attempted to achieve in a document titled, "Commitment To Our People". This document forms the cornerstone of their efforts to break down the walls or barriers that were created between people who operate under the traditional functional "homeroom" mentality. This program was piloted at the program under study. Strong leaders have been promoted from the program to corporate positions. At this point, the reorganization around teams displayed on the program was widely adopted by other programs in the company.

A notable event in the program's life resulted in significant quality improvements and cost reductions when the relocation of product development and design engineers in 1992 resulted in collocation of the engineers to where the product was manufactured. IPT teams were initiated later in that same year.

There were three levels of IPTs. The Leadership IPT was the highest level within the program and it was comprised of the Program Manager, Integration IPT members, Finance, Marketing and other support managers. This team meets weekly to discuss strategic planning and significant program developments. The Integration IPT was the next lower level and was

[25] The program management visited many organizations outside of the aircraft industry such as Motorola and Alcatel.

comprised of the Operations Managers from the four major quadrants: Production; Product Support; Design and Development; Applications and Weapon Systems. This team met weekly and was used as a medium to communicate information among the four quadrants, implement program objectives and resolve operational issues. The Operations IPT met daily to execute program operations and to resolve day-to-day problems. The Operations IPT was comprised of the Operations Manager and each product IPT leader in that quadrant. Since the product was divided into four natural hardware groupings, there was a product level IPT for each hardware grouping in the Production operations quadrant.

The company's first attempt at the implementation of teams was on this program in 1992 in the form of Self-Directed Work Teams (SDWT) which proved to be unsuccessful because the company attempted to implement self-managed work team concepts while ignoring the "soft side" or human element. Although the implementation process was the same for all self-directed work teams, only a few of them were successful while most were not. Production management then conducted 150 random personal interviews with a cross section of employees in order to determine what was happening. The conclusion drawn from these interviews was that success and failure were based on the personality make-up of each team. It was observed that successful teams were largely composed of people who embraced self-directed work teams and were driven by its precepts. Dysfunctional teams were characterized as a group of individuals that did not trust one another and lacked an ability to work together. The first group was described as high initiative. This group supported self-directed work teams because they enjoyed the ambiguity that accompanied it. The second group was described as highly compliant. This group could not handle the ambiguity associated with SDWT and strongly preferred to be told what to do.

Consequently, major drivers that supported the implementation of integrated product teams (IPT) were cost competition with other companies and the failure of self-directed work teams. The following steps were used in the implementation of IPTs:

1. The company hired a leading consultant in the area of team development and benchmarking. With this consultant, the program's operations group conducted exploratory trips to organizations outside of their industry in order to benchmark their organizational structure and to rethink the implementation of teams in their company.
2. Management developed an understanding of the worker's operating environment and functional work silos. They accomplished these objectives by conducting an employee survey called Worker Style Patterns (WSP). These surveys were conducted in a series of workshops used to define: as-is and should-be strawman, core membership of teams, roles of teams and team leaders. The new team structure began operating in 1994.

The WSP survey was designed similar to a Myers-Briggs self-awareness survey where the survey presents the individual with multiple choice answers of which the individual selects the response that best describes his/her personal response. The summary of survey results provided management with an employee description of the functional responsibilities of workers, supervisors and management as well as an indication of individual preferences.

The work culture study results indicated that employees desired: more responsibility, empowerment, budget responsibility, involvement in the decision process, extensive training, rewards based on team performance, the break down of barriers between hourly and salary employees and an increased level of trust among all employees.

For example, in 1994, the Assembly Engineering WSP survey was administered to assembly engineers, their customers and their suppliers in order to understand how this group preferred to work and to define the specific tasks required to fulfill their responsibilities. After the individual surveys were summarized, the program management attempted to align individual preferences with optimal work styles and job requirements in order to maximize employee satisfaction. Poor job/person alignment meant that people had to either change jobs or their jobs had to be changed.

In essence, the program provided a self-selection opportunity for individuals so that they could be placed in positions that best suited their personal nature thereby enabling them to excel. Product designers who enjoyed interfacing with operations personnel could function as IPT members or if they preferred working by themselves, they could continue to do so on advanced technology development projects. The next phase of this program was to create an environment that supported the rotation of designers through production in order to transfer manufacturing learning to the product development phase.

The process of selecting team leaders for IPT was exhaustive. The first step the company used to select team leaders was to construct the optimal team leader profile by surveying all employees for their preferences in leadership characteristics. This process was implemented as part of the program-wide Work Style Patterns survey. Management then solicited applications from candidates who would like to be team leaders. The second step was to select and interview 30 candidates. From this first round interview process, management selected 10 individuals based on leadership and team skills. Management then interviewed these 10 individuals and selected 5 of them for additional interviews.

Phase 1.7 Assess Technology Impacts:

In a number of instances the program experienced significant benefits (i.e., improved quality, reduced costs, improved throughput) through the implementation of new technology. By reengineering existing systems using new technology, the company achieved larger benefits more quickly than were otherwise attainable. Value Engineering projects, such as the following example, take advantage of the development of new technology. The justification for Large Scale Integration (LSI) integrated circuits was based on the elimination of discrete components and their assembly into an integrated printed circuit board. Furthermore, the technology investment decision analysis was often easier to compute in economic terms.

An example of the impact technological progress had on this program was illustrated in the history of one module. The continuous evolution in design of these printed circuit boards (PCB) from hand solder based designs to the current polyimid thru-hole wave solder based design and the replacement of point-to-point wiring with ribbon cable assemblies helped reduce touch labor in this cell by 90 percent.

Phase 1.8 Establish Linkages with Supplier and Customer Base:

The same effort as reported in stage one was continued here.

Stage Four

Implementing Phase 2 - Factory Flow Redesign (concurrent implementation)

Phase 2.1 Distribute Information:

Information was distributed with program status reporting which featured reports of the preparation steps leading to *Kaizen* events. These events required pre-event training, information dissemination and commitment from its participants. People were committed to the process because they observed the immediate changes resulting from these events. Knowing that the results were driven by themselves directly impacted their level of motivation. Employees were less threatened by the reduction in touch labor requirements resulting from *Kaizen* events because of the growing need for direct labor in other programs at the company. However, as productivity in other programs increased, employee job security was expected to become a more important issue in the future.

Phase 2.2 Group Products into Families:

There were four natural hardware divisions of the product. All assembly operation steps were linked to these product divisions.

Phase 2.3 Standardize Processes:

The operation steps in each of the product groupings are standardized. As improvements in the assembly process were accomplished over time the processes became more understood and consistent. There was also evidence that the process steps were followed repeatably.

Phase 2.5 Optimize Factory Flow and Cell Linkages:

The overall process flow was an assembly routing sequence where the linkages between cells were well coordinated. Production achieved after improvements at the manufacturing facility exceeded its original maximum design capacity. At the company, factory flow was designed such that the test equipment, purchased by the customer (Government Furnished Equipment, GFE), would be the bottleneck in production in order to achieve maximum utilization of the most capital intensive equipment. Current product manufacturing lead-time through the factory was approximately one month.[26]

Phase 2.6 Redefine and Redeploy Work Tasks:

One of the unique features of the factory redesign process was that the level of shop-floor employee involvement appeared to be greater in the program than proposed in the

[26] Manufacturing lead-time excludes supplier procurement lead-times which may be up to nine months.

hypothesized model. The members of the improvement teams were very active at redefining and redeploying their work tasks.

Phase 2.8 Construct Cells through *Kaizen* Events:

The process used at this company was a three day workshop process in which a combined supplier/customer team examines a current operation for the purpose of identifying and eliminating waste and non-value-added activities. Once problem areas were identified, synchronous manufacturing principles were used to design an improved, more efficient operation. This process could be applied to any area that uses sequential processes.

These events emphasized immediate, dramatic change and the elimination of waste. Tangible improvements were produced in just days, not weeks or months. The objectives of a event were to: 1) eliminate waste, 2) reduce WIP and 3) reduce floorspace. In a typical workshop, Day 1 is used to define the current state of a process and to brainstorm an improved future state. On Day 2, the change proposal is refined as needed and the changes were literally implemented overnight. On Day 3, the new process was started and initial results were measured and reported.

Four primary metrics - productivity, inventory, lead-time, and floor space - were used to chart the success of the changed process. The average improvements achieved from these events held to date were impressive: 85 percent increase in productivity and reductions of 71 percent, 63 percent and 35 percent in inventory, lead-time, and floor space usage, respectively.

Implementing Phase 3 - Operations Management Development (concurrent implementation)

Phase 3.1 Cross-Train Workers and Realign Incentives:

There was an annual competition among teams to be recognized by executive management as the high performance team of the year. This type of competitive environment created numerous benefits to the company including increased employee pride and ownership over their areas. High performance was defined by a labor index that measures labor performance relative to costs.

The award system was another key element that supported the implementation of teams and IPTs. It had undergone major changes since IPTs were initiated in order to support the changes implemented by the company. This system was developed largely by the efforts of Operations with support of Human Resources. The types of changes that were made required Operations leadership and initiative and could not have been driven solely by the Human Resources department.

Phase 3.2 Reallocate Support Resources:

The program began to transfer quality assurance responsibilities to production workers via its Manufacturing Verification Program (MVP). MVP was an employee certification program that authorized operators to pass work on to the next operation without receiving approval from a quality control inspector. MVP required operators to receive the same inspection training as inspectors. Inspectors audited certified employee output approximately once every five units. If the output failed an audit, then the employee's certification was removed and the employee must be recertified.

Material transportation services were a centralized program but in this program operators moved much of the material themselves as the throughput times were decreased.

Stage Five

Implementing Phase 4 - Process Improvement

Phase 4.1 Improve Process and Operations Predictability:

This program was the first program to embrace SPC. The customer's specification outlining the implementation of SPC was one of the main reasons the program incorporated SPC into its internal processes midway through the program's life. Even though the program was not contractually obligated to implement SPC at its suppliers until later in the program, it did so because management recognized the importance of sharing the SPC methodologies and practices with their suppliers.

The suppliers were responsible for identifying critical material (CM) and critical processes (CP) that required measuring and reducing process variability. These steps were monitored by the company and the government in periodic visits. During this time, the company also drafted a critical suppliers list which identified 30 of its critical suppliers. A critical supplier was a single-sourced supplier that required more than six months to replace and provided high cost products. This list also included internal suppliers. The competitive nature of the program and its greater dependence on suppliers required the company to monitor its process inputs very closely.

Products that flow through the program's assembly processes were verified by certified operators at each operation. Subsystems and final systems were tested in-line. The company used SPC to monitor and control those processes. Over 70 percent of the test operations had a Cpk value greater than 1.33.

Phase 4.2 Improve Process Quality:

The program office also applied SPC techniques to its procurement process in order to measure and improve its performance in this area. The goal of this team was to provide all customers with material and product in a timely manner by identifying, monitoring and improving the key aspects of the program procurement process. This project was initiated in June 1995. This team utilized the company's seven step approach to problem solving.

The team reported process capability, root cause analysis results and pareto analysis at the quarterly Corrective Action Board meeting. The reports illustrated key process errors by source and helped keep the team focused on solving the major problems. One of the long-term objectives of this program was to utilize continuous measurable improvement teams to permanently fix problems in the material procurement process. This process reduced procurement order delinquencies from 6 percent to less than 1 percent.

Appendix D: Case Study Number Four

Introduction

This case study is of a major defense company in the electronic sector of the Lean Aircraft Initiative. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. This case study was conducted on a particular shop within a manufacturing facility. During 1989 this shop was facing some formidable problems. Orders were falling, the product mix was growing, and customers were becoming more demanding (cost and cycle time were expected to drop, quality rise). The shop knew that if they were to become more competitive, it would have to take dramatic steps to reduce costs. The lean changes that occurred over a five year period at this shop are the subject of this case study.

This case was chosen for study because this shop experienced a lean transition which ultimately resulted in reductions in assembly throughput times of 64 percent and work in process levels by 62 percent.

Total Transition Implementation Sequence

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix D Figure 1 shows the process or sequence followed. In this case the performance improvements were characterized by a gradual process of incremental improvements over a five year period. Each box or level in the diagram represents a roughly chronological stage of lean implementation.

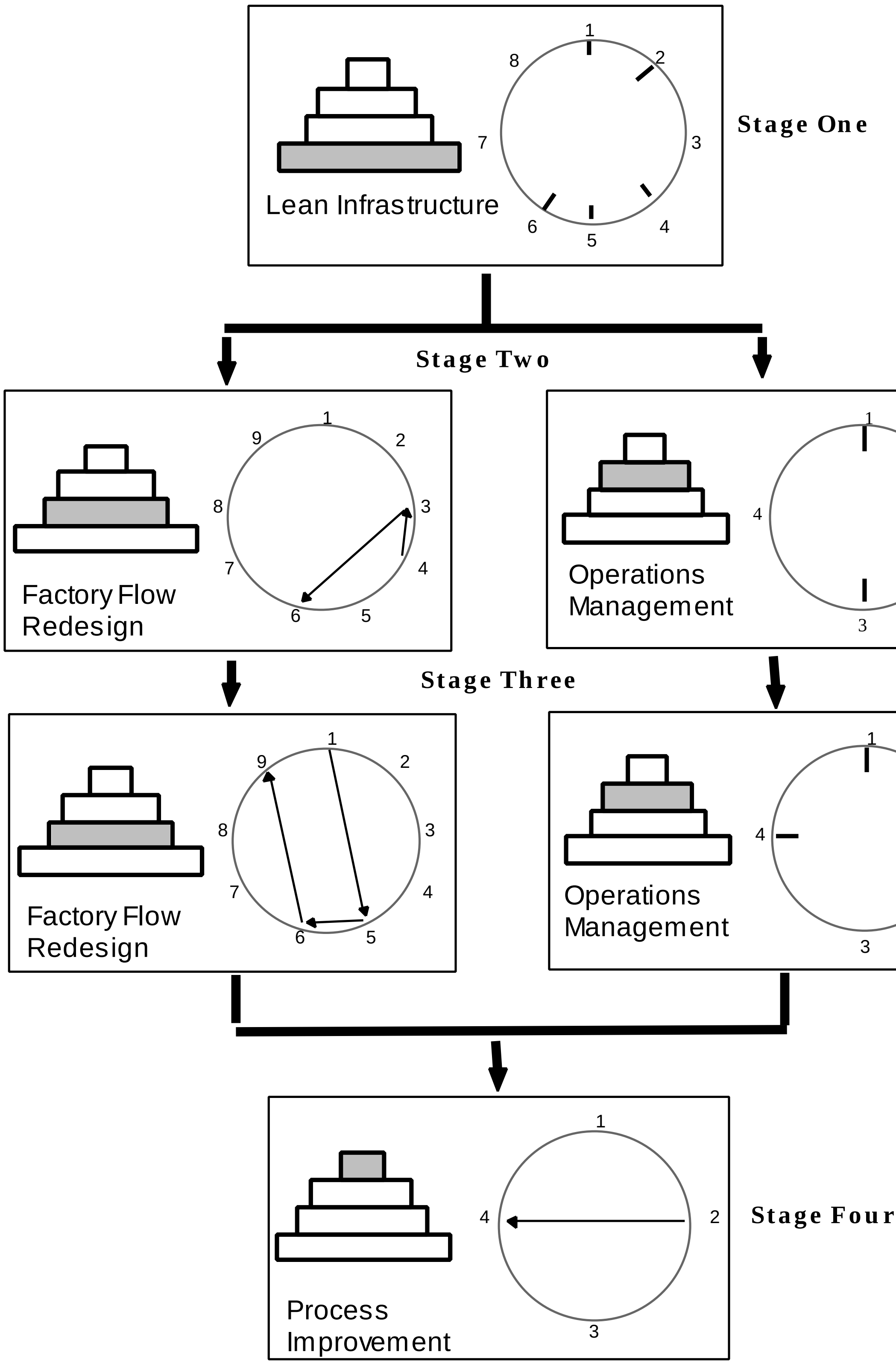
The fourth case study exemplifies the situation the aircraft industry faces. Over a six year period, this company saw falling orders, growing product mix in a given factory operation and the need to reduce production costs. The differences before and after this lean transition were the implementation of work teams, quality improvement teams and several flow process layout changes. This case focuses on continuous improvement which was largely driven by employee empowerment and was set up in the first stage of this transition. Prior to this lean transition the factory operation had control of only 33 percent of the operation steps that processed the products going through the factory operation (in other words, 67 percent of the operations necessary to make the product were completed outside of the manufacturing product manager's area of responsibility).

Improvements during stage two of the transition was executed largely through management actions. By 1990, improvements had reached a plateau and it took a fundamental change to continue improvement. This change marked stage two of the transition which was the restructuring the process layout into product cells and simultaneously giving the workers in the cells responsibility for the production of the product. After the perturbations due to the change of the layout and the culture change of workers in control of the process, improvements continued. During stage two of the transition, the organizational control was increased to 50 percent of process steps.

In stage three of the transition, continuous improvements from work teams contributed to flow time reductions which led to additional layout changes. After the transition the factory operation controlled 91 percent of the process steps required to produce their product. Stage three was characterized by a near pull flow system using *kanbans*. The product is not introduced into the factory unless all components are available. Only two hours of work are taken by employees at one time with a first in, first out working order. Flags are used to indicate need for work in the cells. Kanban boards with preset management limits indicate the WIP accumulation at bottlenecks.

After stage three the factory operation was completely visible. By walking the floor a novice can see the status of manufacturing with problem areas highlighted for everyone to see. The workers load the factory operation. Based on an MRP II window of opportunity, the workers at the first operation determine what to introduce into the factory using process knowledge and daily takt meetings on cell status.

Finally, stage four is marked with improvements in quality and further flow time reductions. Quality improvements have materialized not by focusing on quality but by continually improving flow time and reducing WIP.



Appendix D Figure 1: Case Study Four Implementation Sequence

Stage One

Implementation of Phase 1 - Lean Infrastructure

1.1 Identify business issues/goals and develop a strategy:

In the first stage the shop came to the realization that something new had to be done. After several studies and iterations of attempted improvements, the shop reached a point where improvement efforts had stalled. Performance metrics of WIP and throughput time were static and normal approaches were not producing improvements. It was clear that something different had to be done. The shop decided on a strategy of workplace modifications using the Industrial Modernization Incentives Program (IMIP) as the means to this end.

Early in the lean infrastructure stage the company had set the stage for change implementation by establishing an interactive goal-setting methodology between management and its employees. This process was used to set the shops own strategic goals each year. The planning team consisted of: customers, warehouse and test representatives, the production manager, operators, the business unit managers, shop employees from other company locations (to give an outsider's perspective), and engineering. This yearly strategic plan was an in-depth effort complete with action items and dates. Facilitators and champions were established to represent various strategic topics, to ensure that nothing significant was left out of the plan. Once the plan is completed, it is presented to management, who made suggestions and approved the completed plan. While upper management made suggestions, serious revisions were rare at this stage. The yearly plan was a tool that helped bring long range planning down from the high levels of the organization and give floor-level employees input into the goal setting process.

1.2 Perform benchmarking:

The first steps toward achieving these goals was an identification of internal cost drivers and improvement opportunities, while benchmarking other board shops to find best practices. The IMIP team identified cost drivers and consolidated the results into seven distinct projects. Opportunities to decrease the cycle time and WIP were also identified and ranked based on the program's ability to bring about improvement and on the perceived cost significance of the opportunity.

The benchmarking activities involved studies of 10 other shops. Six of these shops were owned by other companies, while four belonged to other operations of the company. The benchmarking results showed that one company had great success by switching to cellular work units. In this case, a work cell was a self-contained manufacturing unit, where the operators concentrated on building a specified series of products and processes the skills and equipment to perform the majority of the processing. The entire production process was divided into a series of work cells that processed their own parts.

1.4 Identify current and needed skills:

By studying their benchmarking results, and analyzing their current work practices, the shop was able to complete their list of opportunities for internal improvement. Examples of some of the opportunities listed include: more operator training, reduction of cycle times, destroying functional silos in the organization, etc. Before taking any actions, the IMIP steering team completed their comprehensive plan for the project. The plan included establishing estimated costs along with implementation steps and dates. The detailed implementation plans specified instructions for: training, relocation of equipment layout, equipment purchases, and changes in processes, in addition to other important steps.

1.5 Fill skill gaps with corporate wide training:

In order to implement work cells additional skills had to be developed. The company trained the operators in cellular manufacturing and team building skills. All classes were taught by the company's internal certified instructors, using an outside firm's training materials. The classes were short courses tailored to the teams' needs. Operators completed courses in: teamwork, cell skills, problem solving, SPC, holding effective meetings, and conflict resolution, among other topics. Meanwhile, manufacturing management and the facilitators took classes in change management, coaching, and leading problem solving activities.

1.6 Breakdown stovepipe mentality:

According to some of the operators that made the successful transition to work cells, there were growing pains associated with the change to self-directed teams. The most difficult part of the transition for the operators (who were used to accepting orders from a single supervisor) was putting personality differences aside, becoming business-minded, and running their own cell. The operators were now responsible for maintaining a team relationship, where they jointly developed solutions to problems, rather than accepting their direction from a management representative.

Some of the cells were more successful in transitioning into self-directed teams than others. None-the-less, the majority of the teams required a significant amount of time to become accomplished decision makers. It took 6-9 months for all of the areas to fully transition into functional self-directed cells. While the operators were charged with making their own decisions, they did not feel like they were on their own. The managers could still be approached for guidance, and it was important for the operators to know that the managers were there to fall back on. The four facilitators also attended team meetings to help provide cell direction. This combined support helped the teams become confident in their own teaming skills, while providing feedback to the decision-making process.

Before the IMIP, the production areas were organized functionally, creating a lack of ownership. Once cellularization was introduced the effects of problems became more apparent to other members within the cell. Working with one board program helped the operators become familiar with reoccurring problems and helped them make more program improvements. Cellularization also provided more variety in the work that operators perform. It empowered the operators by allowing them to understand the process, and gave them responsibility for the whole operation, not just one operation step.

Stage Two

Implementing Phase 2 - Factory Floor Redesign

2.4 Design process layout and simulate flow:

The shop management ran simulations to determine the ideal number of cells and labor levels on each shift. Based on these results the flow of the products was defined.

2.3 Standardize processes:

Based on the results from the simulations, the processes steps were standardized to accommodate the flows that were defined by the cell arrangement. The actual operations did not change but the method by which the work was organized did change (i.e. in cells).

2.6 Redefine and redeploy work tasks:

Once the cells were in place, the IMIP steering team decided that they would look to reduce other sources of waste. Three examples where steps were taken to reduce waste were: combining the procurement and production control functions, increasing the shop's ownership of the external processes it relied on, and reducing processing times.

Traditionally, the production board areas in the shop relied on a separate procurement group to order their parts. Over a two year period, procurement was integrated into the manufacturing area, to improve communication, reduce the number of people required to order parts and give feedback to the customers, and to give production more control over the vendor relationship. Now manufacturing controls the buying and scheduling functions. A manufacturing representative works directly with the vendors, giving faster response and better follow-up to quality problems. This responsiveness is important, since the shop’s largest defect problem is supplied component failure at in-circuit test. With manufacturing becoming a larger part of the supplier relationship, the shop developed much closer ties to its vendors. The shop provided help to suppliers through its supplier management team.

Early in the this stage of the transition, the shop had little ownership of the production process. The shop only had control of component prep, component stuff, flow solder, and the board QC functions. The individual programs controlled procurement, the warehouse kited the components, and final assembly added parts, and tested, inspected, and coated the boards. Over a three year period, the shop integrated parts addition and in-circuit test from final assembly, and picked up the functional test and coating processes from assembly as well as procurement (as discussed earlier). By owning the processes, the shop controlled the process flows and one manager had responsibility for the entire production cycle.

Implementing Phase 3 - Operation Management Development

3.1 Cross-train workers and realign incentives:

The cells transformed the way that production handled manufacturing nonconformances. Rework areas were eliminated and defects were returned from test (or the customer) directly to the appropriate work cell for corrective action. With this immediate feedback, operators became a large force in eliminating sources of defects. This feedback, along with the additional operator planning responsibilities gave operators much more pride in their work.

During most of the transition, the company had a fairly standard compensation program for its employees. The compensation included a base salary, non-periodic raises (merit bonuses and base pay increases), and profit sharing. Near the end of this portion of the transition, a new compensation program was introduced to give the operators the incentive to improve their knowledge level and optimize their cell's operations.

The new incentive program was a pay for knowledge and pay for performance based program. The pay for knowledge program was intended to provide the employee additional knowledge in planning, process/quality improvement, administration/supervision, etc. The pay for performance program involved quarterly payouts based on a cell's performance versus their goals. While pay for knowledge and performance sounds like reasonable incentives, in this situation, both of these programs were not as successful as planned because the incentive scheme optimized the individual cells at the expense of the whole area, not encouraging cells to work together.

3.2 Reallocate support resources:

The move to cellular manufacturing eliminated the shop's reliance on production control employees. In the past, incomplete component kits were released to the shop. Products built from incomplete kits could not make it through the area and had to sit in a delay pile. Once the proper parts arrived, production control had to locate the incomplete board kits and add the missing components. Through IMIP, kits that are shorted components are not released to production, reducing delay WIP and eliminating incomplete kit tracking. Cellularization also meant less part travel, reducing the need for production control to track and move parts.

3.3 Implement manufacturing information systems:

The IMIP placed computer terminals within each cell to provide a built-in support network for the cell teams. Terminals were used to: log inspection reports, check "how to" assembly instructions and assembly drawings that the operator can zoom in on, listed rework / repair procedures, ordered replacement parts, and to kept track of worker labor hours and board traceability. These were all services that were provided by numerous support employees in the past.

Stage Three

Implementing Phase 2 - Factory Flow Redesign

2.1 Distribute information:

Early in this stage, a eight person Continuous Flow Manufacturing (CFM) core team was formed to plan and implement the shop's transition to a CFM system. The core team consisted of: a methods engineer, two internal consultants, an operator, a facilitator, a shop manager (who served as the core team leader), a customer, and a quality / test engineer.

The core team internal consultants provided the information about the CFM program and helped facilitate the core team during the transition process. The following methodology was used:

1. create proposal
2. engagement preparation - project kickoff
3. line analysis - steps taken to understand the process
4. work plan - list opportunities (as stated by operators and team members)
5. simplification - implementation teams execute improvement work plan for 8 weeks
6. pull system - design, develop, and start system

2.5 Optimize factory flow and cell linkages:

The core team was surprised during the line analysis. Team members thought they knew how the operators performed their jobs, but during step three (line analysis to understand the process) they realized that they didn't really know what the operators did during the day. As the team tackled step four (developing a work plan), the opportunities were organized by problem type (operator, equipment, personnel, etc.). For step five (simplification), the work plan was divided into six categories to be addressed by six different implementation teams:

Implementation Team	Team Issue
1. component prep	prep consolidation
2. test	downtime
3. conformal coat	cure time
4. documentation	eliminate non-value added documents
5. release	shop loading
6. parts	parts shortage

Each team was made up of 3-6 people (with one of the core team members on each team and at least 1 operator). These teams evaluated various aspects of the operation for improvements within individual sections of the shop or outside of the shop.

2.6 Redefine and redeploy work tasks:

The core team and the various implementation teams developed a plan to improve the flow of products through the shop.

2.9 Make product flow visible within the cell:

The visual flow system was part of the pull production system implemented at this shop. The major part of the pull system involved the loading of the shop with work. The remainder of the flow through the production area relied on visual and operator control of the system. The production control people were removed and operators move boards and controlled the flow of material. Production control used to try to balance the line, but this became too hard and time consuming. It was now very simple to balance the shop due to visibility and the operator control of production.

The cells used flags as *kanbans* to get work orders from component prep. They raised their cell's flag when they needed more work orders and the flags could be seen throughout the area. This provided instant visibility of whether the shop is over or under loaded.

As the cells completed an item, they carried the order (in a tote pan) to the next processing area and placed it on the incoming rack. After initial processing, the tote pans were given color-coded labels that tell which day of the week the board was released to the floor. Since the floor operates on a first in, first out basis, this system instantly told the operator at the next station which boards to work on first. The shop tried to maintain less than three days worth of inventory at any point in the area (no more than three tote label colors on any shelf).

In the rare case of "rush" work, red labels are used to denote priority. The shop has a policy that no more than 6% of the products in the area should be rush. The number of red labels was reviewed daily to ensure this policy was being met. Delayed products were also reviewed daily. These were products that have damaged or missing components (due to a test failure or processing/supplier defect) or were waiting for engineering disposition. Delayed products were kept on special shelves at each cell. The shop's policy was to keep less than 5% of the products on the delay shelves.

If an operator mistakenly picked up a fresh delivery from their incoming rack and worked on it for the entire shift, they would miss working on the oldest order. Therefore, the board shop management stressed to the cell operators that they should only be taking 2 hours or less of work from their WIP rack at a time. Frequently rechecking the WIP ensured that the operators are working on the right orders.

As the WIP reached the bottlenecks within the production area, flow is controlled with kanban boards. The kanban system helped manage the flow through the bottleneck areas and kept operators working on the right boards. There were two kanban boards in the area. The kanban boards had a maximum WIP level for each family of production products and the operators changed the actual WIP numbers as they delivered or removed a product. The kanban targets were set at the start of the pull system planning stage, using a WIP computer model. This model was used by management to make infrequent updates, but the kanban levels remained fairly steady since their introduction.

Implementing Phase 3 - Operations Management Development

3.1 Cross-train workers and realign incentives:

Management introduced a new shop-wide pay for performance program. The goal of this new program was to reduce cost and cycle time for the *entire* board area, and not just individual cells. Performance was now measured on labor dollars per component inserted and dynamic cycle time (the ratio of average work in process (WIP) divided by throughput time).

The old incentive scheme optimized the individual cells at the expense of the whole area, not encouraging cells to work together. Since connected cells stressed close ties among the cells and optimization of the entire shop, this old plan was a barrier.

However, the new compensation program provided the right incentives for further process improvements. The new pay for performance program was not only meant to give incentive to operators, but also included the quality control, test, and the administrative support personnel (facilitators, business unit managers, engineering, etc.). Therefore, all of the employees that had a stake in the success of the shop floor became part of the new compensation program, adding incentive for the shop to work together.

3.2 Reallocate support resources:

An operator self inspection program was used to reduce the shop's reliance on inspectors, and to build, rather than inspect quality into the boards. A pilot class was trained first, followed by other areas as the trainers had time. Training involved 20 hours of operator certification quality training, along with 40 hours of military standard 2000 solder certification. The training sessions were followed by a period of daily audits. Audits for experienced areas have fallen to once every two weeks. The operators are recertified yearly after 16 hours of mandatory annual Military Standard 2000 training.

Operators with habitual problems have their stamps removed and have to go through additional audits. If quality problems continue, the operator has to be trained again. The shop has removed stamps from some operators, but has not had to retrain any yet.

3.4 Implement "pull" production systems:

The first step in material flow through the shop was the MRP scheduling system. While MRP is an infinite capacity model and is too cumbersome to plan a dynamic pull system, the shop used it to order components and gave the shop the authority to work on orders. The shop used a 4-week ordering cushion to level loads, but realized this is not optimal, and would like to reduce the cushion further.

The MRP system gave a release date for a kit of components. Once an order fell into a prespecified release window (a certain number of days before being due), it was "fair game" to be kitted and released to the floor. The warehousing personnel pulled the kit on demand. They did not pull partial kits (to keep incomplete boards from sitting in production) and only pulled parts for one kit at a time in the store (to keep parts from being mixed between kits).

Having the ability to pull its own kits has been crucial in the reduction of WIP for the shop. In the past, the programs pulled the kits, so work just "showed up" on the floor. In this case, kit pullers were used to control the introduction of orders to the floor. Kit pullers were operators that order the kits from the warehouse personnel. The pullers knew the complexity of each board and the production time from experience, and combined this knowledge with the cell requests for work, kanban data, and MRP release window to select when and which work to pull into production.

Lot sizes were set as small as possible while remaining efficient. The largest lot size was 20 items, but most lot sizes were in the 4-8 range. This average lot size signaled a large reduction from lot sizes ranging from 50-100 in the past.

The importance of the kit puller in the overall flow of shop work cannot be overstated. They controlled the flow of work onto the floor based on capacity and availability. A poor kit puller could starve the shop by underpulling, or flood it by overpulling, while an accomplished puller can maintain low WIP levels and keep material flowing smoothly through the shop. Each business unit has its own kit pullers that are familiar with a family of products and are linked to certain cells. The pullers work together to keep the cells busy.

Stage Four

Implementing Phase 4 - Process Improvement

4.2 Improve process quality:

Since WIP was reduced, rework has had a significant effect on cycle time. Rework was not a concern in the past, since the large WIP kept the processing areas full of work. In this case, if several boards were returned from a testing area to a cell for rework, the processing step following the test area would be starved for work. Furthermore, the WIP in front of the cell would begin to grow (raising the WIP's queue time, and thus cycle time). Therefore, the reduction in WIP necessitated a high level of quality to keep the cells busy and achieve a low cycle time. The shop was also less reluctant to scrap defective boards than in the past, since the shorter cycle time allowed production to get a replacement board into the system quickly.

The shop shifted to focusing on processing defects, rather than individual part number defects. The business unit managers tracked this data and organized teams to attack common processing problems. Managers reviewed this data rather than operators, since floor level review of too many metrics was considered a non-value-added step.

4.4 Increase process speed:

An example of an implementation team action that improved the process speed was the reduction of conformal coating time. Prior to immersion in the coating fluid, certain areas of the boards were masked for protection. The traditional masking compound took 8 hours to dry onto the boards, leaving the boards sitting in storage for at least a shift before they could be coated. Once coated, the compound did not peel off easily, and an operator had to "touch up" the board by removing the excess compound.

The conformal coating implementation team replaced this traditional masking compound with a new “seal and peel” compound that allowed boards to enter the coating process within moments of application. The seal and peal could also be applied and removed much easier than the traditional compound and did not require any board touch up.

The conformal coating implementation team also changed the board coating policy. In the past, a standard board cure time was prescribed once the board left the conformal coating tank. The team changed the conformal coating policy so the cure times varied, based on board thickness. This cut the average cure time in half. The new curing policy, along with the seal and peel application reduced the average board processing time in the conformal coating area from an average of 52 hours down to an average of 22-25 hours.

Appendix E: Case Study Number Five

Introduction

This case study is of a major defense company in the airframe sector of the Lean Aircraft Initiative. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. In this case study, the company had a large number of flow paths and a low production rate. The lack of processing and flow repetition make it difficult for component producers to maintain low levels of work in process (WIP) and to produce parts quickly and flexibly at a low cost. Merely tracking and managing the numerous part flows was a confusing and expensive process. Also, carrying high levels of WIP was inefficient and costly. The capital cost tied up in inventory alone was expensive, but was only one of the costs associated with WIP. Some (but certainly not all) of the other costs of holding excessive inventory include: warehousing, expediting, and material handling costs, as well as control systems and factory space, and damage, obsolescence, and rework costs. This company adopted the concept of focused factories to answer these issues.

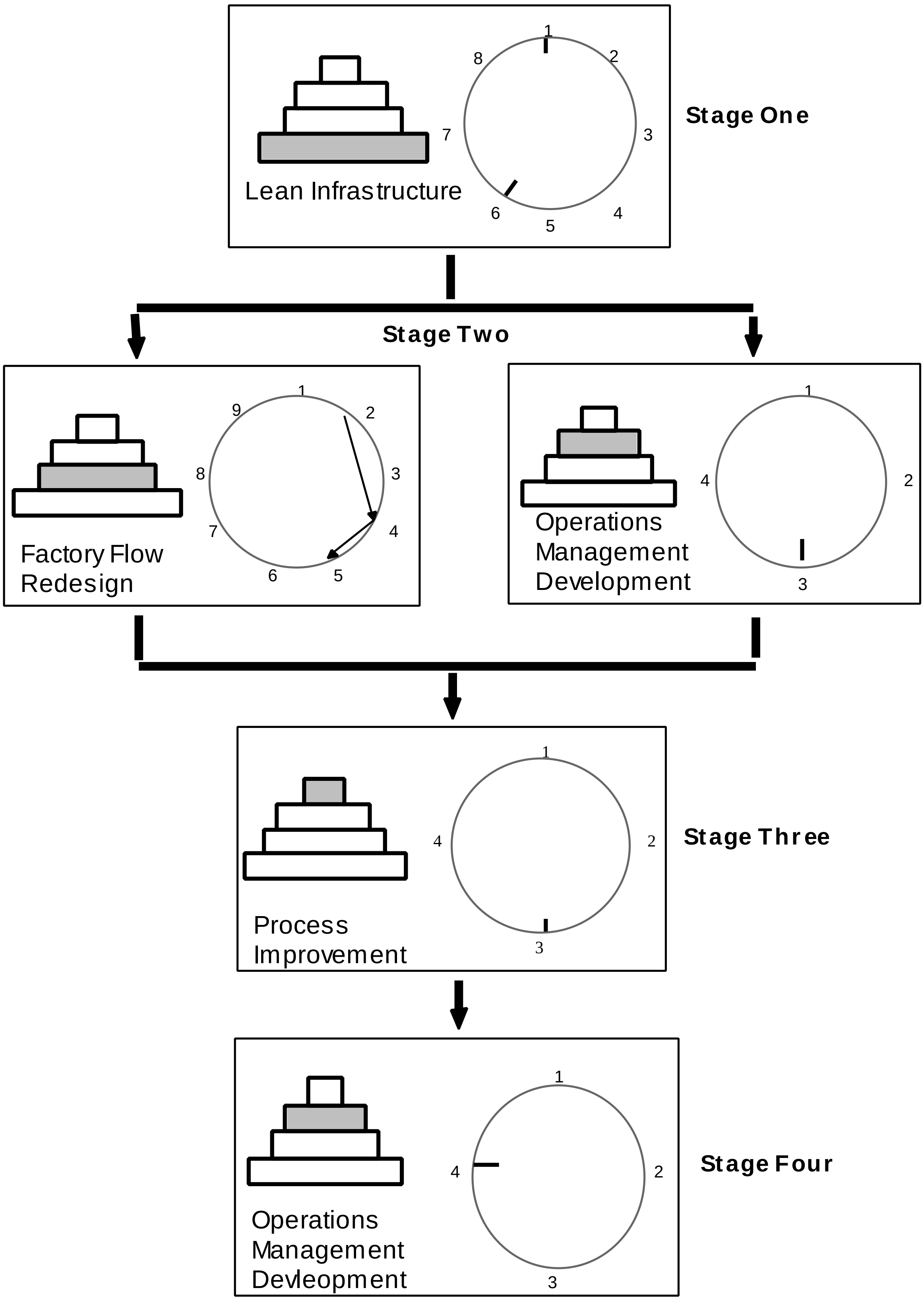
The analysis of this case study focuses on the company's transition from a process focused (or functional) cost center to focused production areas defined by the products in the area. This case was chosen for study because throughput time was reduced by 83 percent and work in process inventory was reduced by 94 percent.

Total Transition Implementation Sequence

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix E Figure 1 shows the process or sequence followed. Each box or level in the diagram represents a roughly chronological stage of lean implementation.

In stage one of this implementation, the company supported a small team of production managers and engineers who defined a program for the company to transition to leaner operations. In this process this team overcame significant cultural resistance to develop a plan to redefine how products were produced in their factory. This plan was focused on the highest sources of waste with which they could effect change.

In concurrent activities of factory flow redesign and operations management development which marked stage two, the team identified an area to implement their ideas and created the first focused factory. Though some innovative use of information and part handling systems, the team reorganized an area to match authority with responsibility about a common product family. After the establishment of a focused factory, stage three was marked with process improvements through experience with the new system and employee inputs. Finally, stage four was marked by the establishment of a raw material pull system.



Appendix E Figure 1: Case Study Five Implementation Sequence

Stage One

Implementing Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy:

During the late 1980's the company established a program to help the company improve its performance. This program centered around implementing lean practices throughout the organization to eliminate waste. As a first step, the potential sources of waste were identified to determine where the use of lean practices could have the most impact. The sources of waste identified were:

- product design - poor designs and long development cycles
- product control - production, material, and management control
- methods of making the product - machines, processes, planning, and tooling
- personnel obstacles - contracted labor regulations and individual employee work practices
- systematic and random errors - processing errors that affect product quality

The company identified the first three items above as the largest sources of waste. The company's strategy was to focus on these three items first, since they promised the greatest opportunity for waste reduction. It was felt that personnel obstacles and systematic and random errors were small compared to the other sources of waste and therefore should be addressed over the long term through contract negotiations, employee training, and process improvement efforts.

The largest manufacturing sources of waste were product control and the methods of making the product. When searching for lean practices to reduce waste, members of the company's team decided that the primary goal should be to eliminate WIP waste by optimizing the process flow. It was obvious that some of the lean practices could not work at the company. For example, there were too many complicated process flows to employ a *kanban* system in the fabrication area. Eventually, a concept known as the focused factory was adopted since it embodied many of the lean practices while meeting the company's production needs.

The focused factory concept as defined by the company is a matching of authority with responsibility, providing the right production tools, materials, and plans at the right place and time. The focused factory redefines management responsibility from a single process to an entire product family flow. Therefore, the goal of the focused factory is to place all processes involved in producing a family of parts into one area under the control of one manager. The focused factories use a computer flow simulation run nightly to determine the build needs, providing better control of the process flow and the opportunity to make faster scheduling adjustments.

Shifting from the company's traditional process-focused (or functional) cost centers to focused factories involved a reengineering of each production area. Management and engineers were responsible for generating gains from this reengineering. However, waste reduction was not limited to reengineering activities. Once the focused factories were in place, management and line employees were responsible for continuous improvement within the focused factory.

Phase 1.6 Breakdown stovepipe mentality:

Focused factories required a change in organizational structure from individual process to product family management. The focused factories could not have been implemented without this organizational shift, since the concept makes one manager responsible for the entire product line, allowing them to concentrate on optimizing the process flow. Bringing the processing equipment together into one area while maintaining the old management structure would have spread the machinery location and the management responsibility even further than the old cost centers and would only have caused confusion.

While corporate cultural change was not the goal or necessarily a byproduct of the focused factory implementation, an acceptance of change needs to be present within the culture for a successful implementation. While some of the company's management had to fight hard to implement the focused factories, the company's culture was not so impervious to change that they were fighting a losing battle or failed.

The focused factories have given the production area more power. Aside from the improved control of tools and scheduling mentioned earlier, the focused factories have provided better control over maintenance and processing. Most of the focused factories have a "dedicated" maintenance person who answers all of their calls (as well as calls in other areas too), providing better response and consistent machinery repair.

Since much of the necessary processing equipment is found within the focused factories, components usually do not need to be moved across the facility for processing. When parts leave the focused factory for processing in other cost centers, they have to be handled multiple times as they move between factories and across docks. Even large parts get lost, and the cost centers often concentrate on hot orders, neglecting the focused factory orders until they become hot. By the time these orders return to the focused factory, they are far behind schedule. When the focused factories were first implemented, moving parts to other areas for processing accounted for 25% of the flows. It currently accounts for 10% of the flows, with the goal being 0%.

Stage Two

Implementing Phase 2 - Factory Flow Redesign (concurrent implementation)

Phase 2.2 Group products into families:

Before focused factories could be laid out, engineering selected the equipment required to support the area. Common component processing flows between this equipment were identified and the layout of the focused factory was optimized around the most frequent flows. The area was organized so part movement was not restricted by barriers and the work areas within the focused factory were visible and accessible. All machinery was placed close to aisle ways, so parts could be easily transferred between machines. For example, an aisle down the center of the area was used to facilitate WIP flow. Depending on the machinery identified to build the focused factory, some of the equipment was added from other company processing areas outside of the fabrication plant, but most of the machinery came directly from the fabrication cost centers within the plant. As the machinery was moved, older equipment was rebuilt, while some were replaced with newer machines.

As the equipment was relocated and the cost centers were transformed into focused factories, improvements were made to the production areas. Additional lighting was added, the machines were painted white and the floors are painted light gray to provide a clean and well-lit work environment. Power and air supplies were added to all support columns (even if a machine is not planned to be installed close by), to give the focused factory flexibility if later equipment relocation were required.

Phase 2.4 Design process layout and simulate flow:

The first of the company's focused factories was the small extrusion focused factory. Small extrusions are any extrusions of less than 28 inches in length. Most of the extrusions in the small extrusion focused factory are aluminum and some of the focused factory's processes include: sawing, milling, routing, sanding, and deburring.

The focused factory was formed from part of the original extrusion cost centers. These cost centers had some of the most complex processing in the plant. Combined, the extrusion cost centers accounted for approximately 20 thousand part numbers, and had some of the highest costs and the lowest efficiencies. The small extrusion area was selected as the first focused factory due to its low risk and high potential for successful cost reduction. The risk was low, since management could exert complete control over the processing flows through the automated material delivery system discussed below. Furthermore, the company's management calculated that a small extrusion focused factory would pay for itself within a period of three years or less.

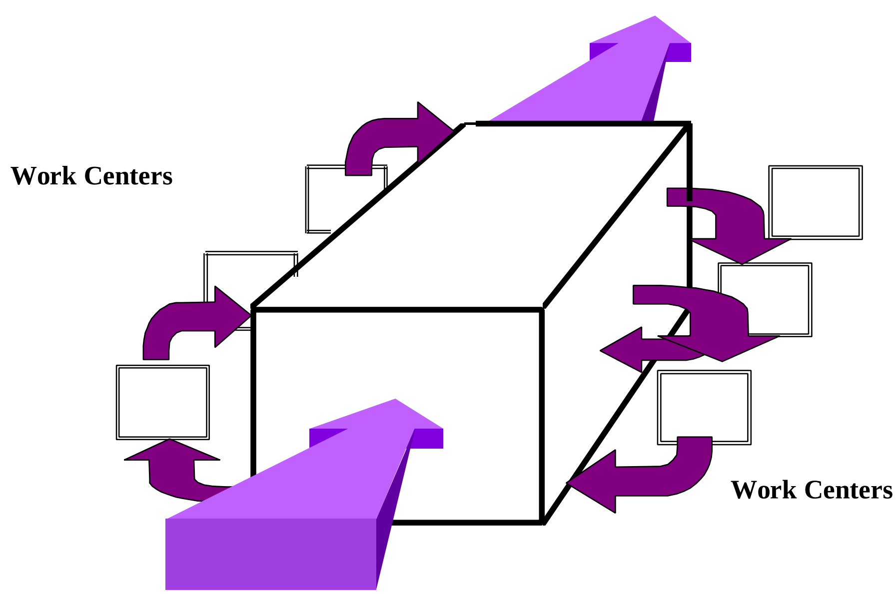
During the planning stage for the focused factory, parts were separated into small and large extrusion categories. These categories were selected because of the similar material handling characteristics of like-sized parts. Once the parts were separated, common processing flows were identified. Common flows helped the engineers optimize the location of existing machinery and equipment added to the focused factory from other areas.

Engineering found that the small extrusion focused factory had such a large number of distinct flow paths, that it was not possible to develop a conventional floor plan with an aisle way to move parts around the area. Instead they began to research automated material movement systems that could efficiently move the components to the proper processing stations. Two systems were identified: one was a system of conveyors running between work stations and the other was a totestacker system, using a crane-operated material storage and delivery system. As the two systems were evaluated, the engineers found that the totestacker system better met their needs. The conveyor system was unsafe and prevented employees from freely moving around the production area, while the totestacker system could easily move parts between work stations without affecting the operator.

Phase 2.5 Optimize factory flow and cell linkages:

The company purchased a double totestacker system for the small extrusion focused factory. The totestacker is a 3-dimensional random access delivery system that functions like a "black box". Components and tools are stored in the totestacker and delivered where they are needed, when they are needed, regardless of processing equipment location. This "black box" facilitates a random routing of parts and effectively turns the many discontinuous flows into continuous flows. Appendix E Figure 2 shows how the totestacker creates a continuous flow through the production area.

The Totestacker Creates a Continuous Flow



Appendix E Figure 2: Totestacker

The totestackers are both two stories tall and are located directly across from each other. Machinery and work stations were installed between the totestackers on both floors. The WIP and tools are stored and delivered between work stations in totepans. As a component or tool is put into the totestacker system, a bar code ties it to a totepan. The bar code is also used to tie the component to a job. The totestacker system understands each job's processing sequence and automatically follows the production schedule to move the pans to the proper processing stations. The crane pushes pans through ports located in the sides of the totestacker, into the processing area.

The totestacker has other benefits beyond solving the company's multiple flow delivery problems. It helps the paint department by storing components (completed in the focused factory) with the same painting combinations together and shipping them to the paint department as a batch. The totestacker also stores approximately 85% of the focused factory's 10 thousand tools (drill and layout templates, router blocks, etc.). This gives the focused factory quicker access and better control of its tools than it had in the past, since the majority of these tools were originally located in the tool crib outside of the small extrusion focused factory. Finally, the totestacker minimizes future layout changes, since no layout changes are required if processing flows change in the future.

Implementing Phase 3 - Operation Management Development (concurrent implementation)

Phase 3.3 Implement manufacturing information systems:

One of the key elements of the focused factory implementation was a strategy to use a software simulation program to perform scheduling of the focused factory. In the past the MRP system performed the scheduling of parts but this system was not designed nor could it keep up with the multitude of changes that occur each day. Therefore, a computer hardware system within the focused factory developed a schedule for the production scheduling that was more accurate and took into account those factors

Each of the focused factories has its own computer that runs daily finite capacity (utilizing the levels of focused factory capacity, labor, overtime, etc.) simulations to schedule the focused factory's production. Since the simulation is advanced enough to understand the focused factory's capacity, it schedules orders by priority and machine availability. If one machine is loaded for the day, the computer begins to schedule other jobs that don't need that machine. The simulation optimizes the flow of orders, so they move quickly through the area once released. The computers running the focused factory simulations are tied to the company's legacy computer programs, that control and update: tooling, material, bill of material, inventory kiting, routing, current location, and expediting data.

The initial focused factory implementation plan required the relatively rapid development and installation of a scheduling system. At first, the company considered using off-the-shelf finite capacity software programs to combine data from the different systems and run a production simulation for the individual focused factories. Unfortunately, though, the software selection was limited, and none of the offerings were robust enough to handle the data load.

The company's development team's scheduling system works in the following way:

1. the company's main scheduling system downloads data to the individual focused factory computers
2. these computers sort through and find their area's production requirements
3. the software calculates a critical ratio that tells what work is needed soon

4. if these parts need processing work completed outside of the focused factory, the computer automatically compensates and moves them ahead on the schedule.

Code changes are installed 2-3 times per month, providing a quick and inexpensive method of continuously improving the software.

In the past, it took up to 2 weeks to alter the shop orders, but since each focused factory runs its own scheduling simulation every night, the focused factories can quickly change the priorities of orders. Priority work is easily identified, since hot (late or almost late) orders are placed at the top of the order list. The system reports make it more obvious than ever before if these orders are not worked on, providing additional incentive for the focused factories to work on priority orders first.

To speed the implementation of the scheduling system into the focused factories, computer terminals were installed with radio transmitters, rather than wires, tying them together. The engineers chose to use transmitters, since installation of dedicated terminal connection lines could have taken over a year. It turns out that this was smart in a number of ways, since the transmitters have actually been more reliable than dedicated lines.

Stage Three

Implementing Phase 4 - Process Improvement

Phase 4.3 Increase process flexibility:

Each focused factory has at least one setup reduction team comprised of industrial and manufacturing engineers, operators, and in some cases manufacturing supervision. These teams have actively attempted to shorten machine setup times as a means of reducing labor hours. The focused factories have benefited greatly from the reduction teams' efforts, since short setups are necessary when dealing with the small production lot sizes that the scheduling system calls for, and since the original setup times are as long as run times on some pieces of machinery. Setup reduction teams often look to eliminate dedicated tooling to reduce setup times. For example, the focused factory's ADRM (or automatic drill and route machine) has automated, flexible fixturing (rather than rigid, specific tooling) that eliminates the need to setup processing tools. Instead, the machine can start milling or drilling almost immediately.

Stage Four

Implementing Phase 3 - Operation Management Development

Phase 3.4 Implement "pull" production systems:

The supplier Just in Time program was introduced to reduce raw material inventory at both the company and the supplier site. Rather than making large order deliveries once every few days, or once a week, suppliers make daily deliveries of the material the focused factory needs for that day only. One example of this type of production was made with the raw materials supplier. The company made this supplier a certified supplier after they demonstrated the ability to consistently deliver quality service and materials. This supplier receives the company's orders and loads color-coded dollies with raw material. The dollies are transported to the company and the dolly color tells production control which area in the factory that will use the material. Since the supplier is a certified supplier, their parts automatically pass through incoming inspection and they receive payment. The old method of parts delivery needed 13 department hand-offs, required 9 managers, and 25 steps, while the JIT program involves 5 hand-offs, 5 managers, and 12 steps.

Appendix F: Case Study Number Six

Introduction

This case study is of a major defense company in the engine sector of the Lean Aircraft Initiative. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. In this case study, a company refocused its energies to creating lean, world class operations, reducing costs and increasing competitiveness significantly. Many of the facilities began using *kaizen* events to make large-scale operational improvements. The following case study focuses on this company's General Machining area, and the changes it has made since 1993.

This case was chosen for study because this shop experienced a lean transition which ultimately resulted in an average lead time for parts reduction from 20 to 4 weeks, a 38 percent reduction in defects per million opportunities, a reduction of 29 percent in customer complaints, and a 24 percent decrease in cost per standard hour. In certain cells remarkable improvements were registered including reduced numbers of machines used, 60 percent reductions in gauges used, a 92 percent reduction in average time per setup, a reduction in WIP by 72 percent, reductions in floor space utilized by 61 percent and a reduction in the distance a part travels to be completed by 58 percent.

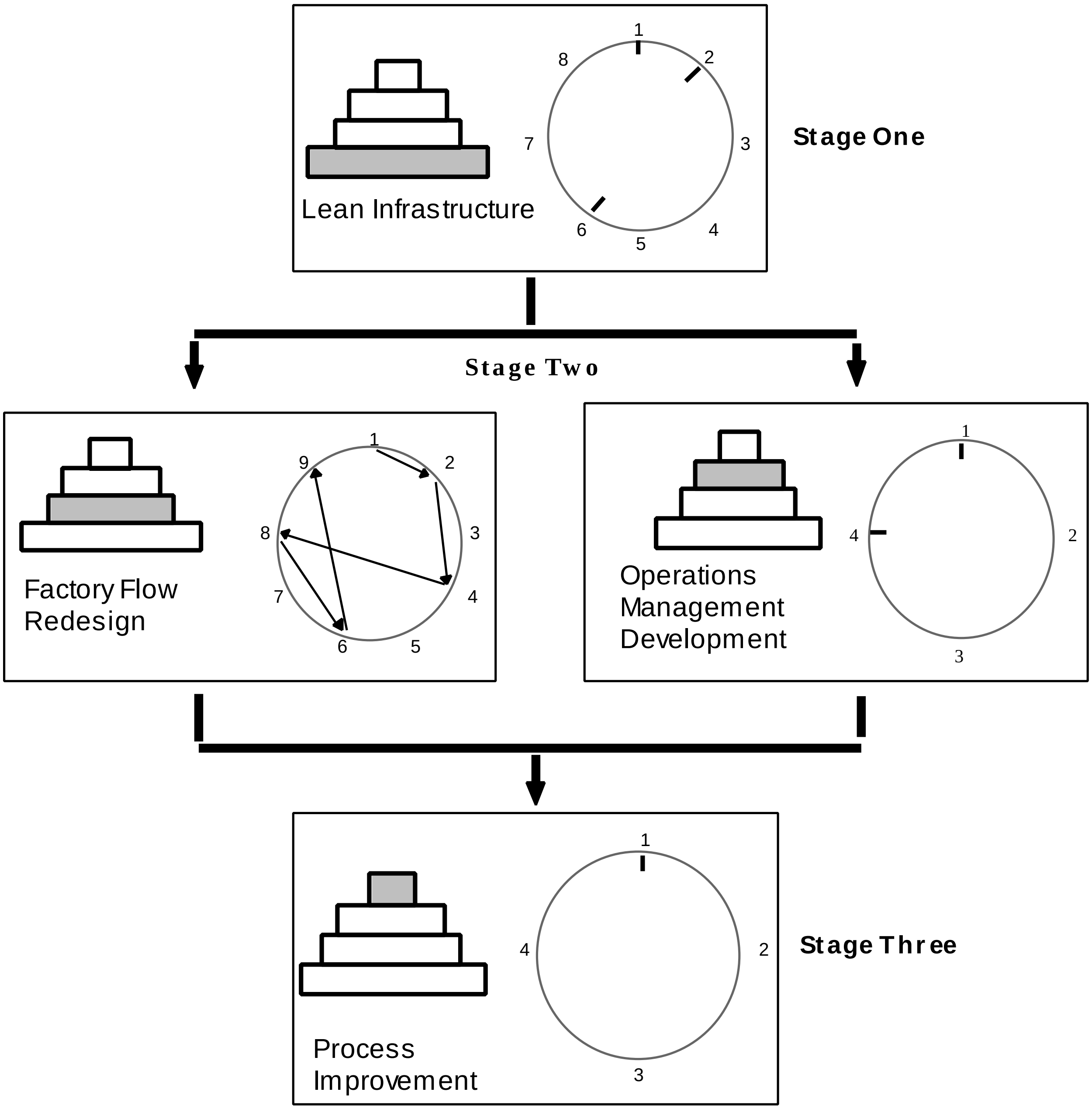
Total Transition Implementation Sequence

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix F Figure 1 shows the process or sequence followed. Each box or level in the diagram represents a roughly chronological stage of lean implementation.

In stage one, the company developed a strategy which was passed on to all divisions. In this case, the General Machining area also developed a strategy for its lean transition which involved the members of the area. The major focus in this stage was on communication of the strategy and the implementation of employee empowerment.

In stage two the factory flow redesign and operations management development phases occurred concurrently. The major emphasis was management's definition of product grouping followed by rapid redeployment of equipment to satisfy a new cellular layout initially designed by manufacturing engineers and later refined with operator *kaizen* events. As part of the layout design, workers were cross trained for multiple operations, and cell management and operators were challenged to implement single piece flow to achieve pull production.

In stage three, the process improvement phase followed the major activity associated with the redesigned layout and concentrates on further refinements to the cell after the initial layout change. Process improvements have come from standardization, multiple *kaizen* events and setup time reductions.



Appendix F Figure 1: Case Study Number Six Implementation Sequence

Stage One

Implementing Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy:

Faced with a dire business situation in 1992, the management of the company's General Machining area decided that it needed to make quantum leaps in a short period of time. To achieve these improvements, the company's old strategies would no longer work. Instead, General Machining established a new strategy to become a world class manufacturing business.

To successfully become a world class manufacturer, General Machining established a three-legged stool strategy. The three legs that support the stool involve operations, new work, and technical strategies. In operations, the strategy was forged in the shape of a horseshoe. This horseshoe is divided into six distinct areas, with cellular manufacturing, JIT, MRP, TQM, and standardization revolving around employee empowerment. This high-level plan was developed by 9-11 employees in a three day offsite planning session. The plan was detailed, yet had enough flexibility to be modified as the company ran into unforeseen implementation barriers.

Once operations improvements are realized and the production areas become more efficient, the new work strategy is to keep experienced employees and equipment working by growing the business. Since operations have become more efficient, the business units can competitively bid on some of the work they have outsourced to vendors in the past. The technical strategy involves breaking down the barriers between engineering and manufacturing, and bringing integrated designs to production quickly. Like a three-legged stool, the strategy cannot stand very well on its own if one leg is too weak. Instead, the three legs should work together to support the new world class shop.

General Machining's management turned this strategy into a vision and mission statement with the help of the business unit employees (both salaried and hourly). The manager of General Machining reviews the mission with all of the employees quarterly, while the business unit managers review it with their entire business unit monthly. Individual cells measure their strategic progress along the horseshoe by using the ten commandments (described later in this study).

Phase 1.2 Perform benchmarking:

In General Machining, benchmarking studies of small machine shops in the local area came to the unsettling conclusion that the shops had the latest equipment, and quality and pricing to make them competitive. Coupled with the company's changing business climate, this study provided incentive for the company and employees to make dramatic improvements.

Phase 1.6 Breakdown stovepipe mentality:

The General Machining area strived to empower the employees at all levels. However, empowerment was not merely used as the latest buzz word that has little meaning in the shop. It was not meant to turn the operators loose, giving them the right to make any, and all decisions as an individual. Rather, empowerment in General Machining has focused on giving the operators the necessary tools and education to become involved in the decision making process.

General Machining attempts to leverage its employee's skills in making improvements by communicating with and involving the operators in the cell's operation. According to one of the business unit managers, "The key is to share the information with the people", and the business unit managers do. Business unit metrics related to delivery, cost, and quality are updated weekly and are posted in the cell. These metrics include:

- cost of capital (used to measure inventory)
- shop consumable usage
- vendor assistance (cost of outsourcing part orders)
- maintenance and repair
- durable tooling
- and direct labor overtime.

The point of use financial data on actual versus budgeted consumables, sundry items, and overtime costs, have helped the cells gain better control of their costs. The entire business unit meets monthly to discuss performance on a cell and business unit level.

As mentioned earlier, operators became an important part of the rearrangement efforts by participating in the *kaizen* events that setup the cells. These events were an important first step in the empowerment process and helped the employees understand the importance of their input and participation in improvement activities.

Operator self-inspections have practically replaced the final inspection quality audits in General Machining. The few inspectors that are left in the cells still perform two types of inspections, detail and visual inspections. Detail inspections verify that the operators performed all of the required inspection steps, and have become a rarity. Visual standards have not been turned over to the operators yet, since they are subject to interpretation subjectivity. The inspectors audit an operator's work based on their past performance. Operators with few inspection failures in the past follow a minimal inspection schedule.

Rather than reporting to their traditional functional areas (engineering, quality, manufacturing, and production control), cell members act as a product-centered team. Cell unit leaders were selected to head this team from the old supervisory ranks, other employees that were interested, and through recruiting. The difference between the old supervisory and cell unit leader positions is that the leaders act as the head of a business, rather than acting as just a job assignor. The cell unit leaders are considered to be one of the key links in realizing change. They control the level of operator involvement and are instrumental in the cell's performance. These leaders had to pass written tests and a series of structured interviews to determine if they could perform the required duties. Some of the supervisors and the early leaders had to be reassigned or let go, since they were not flexible, business-minded, or team oriented enough to hold the position.

Stage Two

Implementing Phase 2 - Factory Flow Redesign (concurrent implementation)

Phase 2.1 Distribute information:

As part of the strategy information about the goals and metrics to achieve these goals were distributed to the entire General Machining area. This was emphasized in total work center meetings as well as business unit meetings. The cells measure themselves in four key areas: quality (DPM - or defects per million opportunities), cost (overtime hours and usage of consumables), schedule performance (on time delivery percentage), and speed through the area (a cycle time figure). The cells also measure their progress against the operations strategy. Ten important strategic characteristics were identified from the operations horseshoe to be tracked on a cellular level. These ten commandments (as they are referred to in General Machining) are:

1. Balanced production
2. Setups / changeovers
3. Standard work
4. Pull production
5. Total productive maintenance
6. Mistake proofing
7. The 5 S's rating (sort, straighten, shine, standardize, and self discipline)
8. Visual controls
9. Employee skills
10. Improvement planning

The cells rate themselves against a detailed rating grid that specifies whether a cell ranks at level 1 (worst) through level 5 (best) in each of the ten categories. This gives the cells a gage of their progress and sight to their goal of completing General Machining's horseshoe strategy for cell evolution.

Phase 2.2 Group products into families:

By the end of 1993, the General Machining area was ready to move from functional processing areas to product-oriented production cells. As the plant's wooden block floor was dug up and replaced with concrete, a team of manufacturing engineers and technical managers were dividing the machining products into families to be placed into separate cells.

Combining General Machining's more than 300 part numbers into cells was no easy feat. At first, the planners tried to combine common flows and part sizes on paper, but this quickly became too complicated. After numerous attempts at assigning part numbers to cells, the planners used a simple planning technique. They assigned color codes to each process, and mapped the complete process flow for each part number in colors on a wall. This made it easier to locate common flows by combining common color combinations, and place parts with the same processing flows into the same cells.

Phase 2.4 Design process layout and simulate flow:

Following the cell / part number assignment, floor space was allocated for each cell and *kaizen* events were held to locate where the machinery should be placed to ensure the best production flow. Before any equipment was moved, the teams placed cardboard squares (shaped like the cell's machinery) on the plant floor to plan the optimal movement of parts through the area. When space in the plant was limited, the teams performed the cardboard *kaizens* in the plant parking lot. This allowed the teams to refine their layout without moving any equipment.

Rearrangement speed was crucial, since it was difficult to meet production schedules during the moves. In the past, equipment relocations were written up, presented to the facilities department, scheduled, and started as facilities labor allowed. On average, these moves took approximately 12 weeks to complete. Instead, tiger teams were established to expedite the move process.

Tiger teams are cross-functional teams comprised of skilled trades employees (plumbers, electricians, millwrights, etc.) along with manufacturing engineers. These teams were assigned full time to the relocation process. They were able to virtually rebuild the General Machining's manufacturing facilities within a one and a half to two years period (80% of the activity took place within an eight month span). During this time period, 1,200 pieces of equipment were moved and approximately 790 pieces were cleaned and reinstalled. The balance of equipment was sold or put into storage. To move equipment at this speed, two or three machines were typically moved down the main aisle at a time, 24 hours a day!

The tiger teams cut this relocation time down to three days, thanks to some creative thinking and input from the employees. These teams were open to trying new movement ideas, since the worst that could happen was that the idea did not work, and the equipment was moved using the old methods. For example, machines were placed on wheels to be rolled down the aisle and parts of equipment that would normally have fallen off during relocation were attached before movement. In one situation, an operator convinced the movers to strap separate parts of his machine together before moving it, saving a considerable amount of disassembly, unwiring, reassembly, and rewiring time.

Moves were made with the idea that cells should be kept flexible and simple. When installing heavy equipment, the tiger teams tried to keep this in mind. For heavy equipment requiring deep, solid foundations, the machinery was placed on large metal plates with an insulation layer underneath instead. This provided move flexibility, speed, and cost reduction. The foundations would have cost $2 million to install, taken a long time to dig, and been virtually permanent, whereas the plates cost only $200 thousand, and could be put into place quickly and easily removed in the future. All of the plant's air, water, and electrical drops were also flexible, in the event of unforeseen equipment moves.

Phase 2.8 Construct cells through *Kaizen* events:

As part of their plan, General Machining used *kaizen* events to move to cellular manufacturing. *Kaizen* events begin with an assessment period, where team members (operators and cell leaders, as well as business unit managers and other salaried employees) study a process to eliminate waste. Once they have identified nonvalue-added steps, the team rearranges the process to remove the waste. The company's *kaizen* events focus on lead time, worker and part travel distance, inventory, and space measurements to drive improvements. The events typically last two weeks. During the first week, the teams of 10-12 employees spend half their time training in *kaizen* principles (the cellular concept, setup reductions, visual control, predictive quality, etc.) and the other half analyzing the production area. During the second week, the teams rearrange the area's layout. The *kaizen* teams do not aim to achieve perfection during the events, but rather try to acquire a 50-60% improvement in the short two week period.

Phase 2.6 Redefine and redeploy work tasks:

Once a cell's layout and installation were completed, production began running. However, production still flowed along functional lines, even though the layout configuration was cellular. This meant parts frequently jumped between equipment. At this point, the cell were ready for the reprocessing stage as the company called it. In this stage the operations sheets and work tasks were revised to fit the cellular layout.

Reprocessing is a means to realize the optimized flow designed during the planning stage. It accomplishes this by reordering part number flows on equipment, changing cell assignments for some part numbers, and moving equipment where necessary. The absence of significant changes during reprocessing in most areas reconfirmed that the original part number assignment activities and equipment layout *kaizen* events were successful.

Phase 2.9 Make product flow visible within the cell:

Since restructuring, the scheduling within some of the cells became more simplistic. The heavy (and often outdated) production control scheduling manuals were replaced with white boards showing the area's production volume for each part number and its backlog based on data from the MRP system. Squares on the floor outside of the production area act as kanban locations to show when the area needs more supplies. Within the area, operators assemble their own production kits from supply bins. When these bins are emptied, yellow kanban cards are used to reorder their contents. Tools and boards are color-coded by part number, to help keep the area organized. This visibility to production flow has enabled a cell to get its programs back on schedule for the first time in recent years.

In another example, all production tooling is kept in the area in racks. In the past, this tooling was kept in a centralized crib. The crib attendant pulled by priority, requiring the departments to request the tools days in advance. Now, each set of tools required to run a job are combined on a large tray. The tray has a thick layer of foam on top that has a spot for each tool cutout in its shape. This visual control makes it simple to see if an operator forgot to return one of the tools, or if a tool is missing from the tray. The trays are easily moved in and out of the work centers on a rolling cart and have their kit number inscribed on the outside. It was obvious to us that the area had spent a significant amount of time making sure that there was a place for everything, and everything was in its place. This is especially important (particularly for tools that can get mixed up or lost easily), since the operators are responsible for stocking and retrieving their own tools.

Implementing Phase 3 - Operations Management Development (concurrent implementation)

Phase 3.1 Cross-train workers and realign incentives:

In the past, the training department was an autonomous support arm, completely insulated from the activities taking place in production. This group was not tied to operation's business strategies.

As General Machining reorganized its operations into product centers in 1993, this situation changed. Trainers were broken out of the training department and were reassigned to product centers. General Machining's trainers became directly tied to the business strategy and the operations "horseshoe." This allowed the training personnel to develop their own strategies based on the product center strategy and the employees' ranking of their own skill needs.

Training to date has focused on giving the managers the tools required to realize the new business strategy, while generating an understanding of the strategic concepts. Managers were provided courses in leadership through values, building partnerships, and coaching, to help them work with the operators in achieving improvements.

The trainers have also created a comprehensive training program for the operators. However, demanding production schedules and cell rearrangement and reprocessing activities have made it difficult to complete this training. The trainers have provided an average of 60 hours training per employee in 1994, an increase from the 40 hours provided in 1993. However, these totals are still below the General Machining targets, due to the lack of available training hours.

The operators are cross trained to perform different activities within the cell. The intent of cross training within General Machining is to drive cell flexibility, quality, and increase employee empowerment. The employees virtually become their own customers by working and understanding a process that is upstream from the process they typically operate. The unit leader decides who will be cross trained on which process equipment, based on the cells needs. Cross training involves one operator training another on the piece of equipment they are most familiar with. It is not common for the operators to be cross trained on all of the cell's machinery, since it is not practical for operators to run all of the equipment in the cell frequently.

Phase 3.4 Implement "pull" production systems:

Within cells a pull production system has been implemented, however the entire area has not yet achieved pull production. With the use of visual controls within the cell a pull production system has been enabled. For example one cell took this concept a step further in order to handle out of sequence processing. This control of production has helped the area deal with late supplier deliveries. If supplier material enters the area after the production launch date, one-piece flow means the cell can quickly flow the order through the area, without the use of expediters and without compromising the schedule performance of other orders already in production.

Stage Three

Implementing Phase 4 - Process Improvement

Phase 4.1 Improve process and operations predictability:

General Machining's continuous improvement program helps cells make further improvements once the rearrangement and reprocessing stages are completed. Each business unit has its own continuous improvement leader who is typically a technical manager. The leaders meet regularly to plan continuous improvement events and choose the department and type of improvement activity that they want to pursue. Continuous improvement leaders usually "shadow" the firm's hired consultants during *kaizen* events to learn improvement strategies in a hands-on environment.

A cell significantly reduced its processing time. Some of the largest reductions came from the cell's concentration on standardization. In particular, the cell focused on standardizing their fixtures with precision pins to locate parts, tools, and budd locks. They also developed self-contained setup kits that contain all of the required setup tools for one machine and quick connect tooling that fits right into place. For example, it used to take 6 hours to setup a buffing machine. Through standardization of the machine's fixtures, the setup time dropped to 10 minutes. Another machine uses setup probing to check tool and fixture setup, dropping the machine's setup time from 8 hours to 30-45 minutes!

Appendix G - Case Study Number Seven

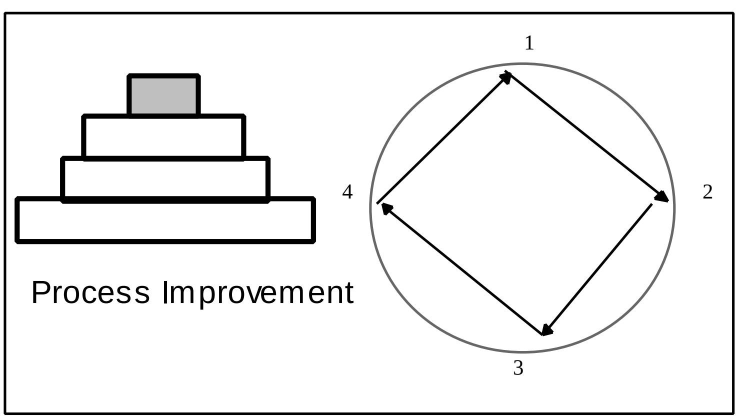
Introduction

This case study is of a major defense company in the airframe sector of the Lean Aircraft Initiative. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. In this case study, a company changed the way in which they manufactured one of its products. In one case craft manufacturing techniques are prevalent and in the other case lean manufacturing principles have been applied. The company has characterized this change as a shift to precision assembly.

This case was chosen for study because the design, fabrication processes and assembly operations yielded a aircraft product that could be assembled without tools in half the time that similar parts had been assembled with significant repeatable results when the part was assembled into the next higher assembly.

Total Transition Implementation Sequence

Following is a description of the implementation sequence observed in this case study company as it became leaner and it's comparison to the hypothesized Lean Implementation Model. Appendix G Figure 1 shows the process or sequence followed. In this case study, only one stage was observed concerning the process improvement phase of the model. This company used key characteristics to focus its efforts. At each key characteristic, it defined the process capability needed to achieve that characteristic and then proceeded to improve the process until the key characteristic was obtained. In this process, the company followed, in sequence, all the steps postulated by the hypothesized model for this phase.



Appendix G Figure 1: Case Study Number Seven Implementation Sequence

Stage One

Implementing Phase 4 - Process Improvement

Phase 4.1 Improve process and operations predictability:

Instead of simply improving on the method of using tools that had been a mainstay of the aircraft industry since its early days, moving toward precision assembly with a low number of tools signaled a leap toward a completely different method of component production. Therefore, precision assembly met with heavy initial resistance with the company and its external customer. These doubting-Thomases (called dinosaurs in this case) were so named, because they only believed in proven production methods and were not willing to try unproven techniques, especially in the risky early period of a new program. Around the same time, the customer began asking its suppliers to use SPC for the program. The company formed SPC teams to find the best way to integrate SPC into their operations. One of these SPC teams found that the company's manufacturing processes had too much variability to meet tight clip tolerances of (+/-) 0.010" or less without using tools.

The dinosaurs were in their glory. They didn't believe an SPC program or manufacturing without hard tools would work, and early developments seemed to support their case. The situation looked bad for precision assembly, but the precision assembly team that supported the concept held firm in their belief that it was the best way to meet Boeing's needs. Soon after their first study, the SPC team performed another study to see if they could decrease process variability.

The team understood that without additional control over the assembly process, pursuing precision assembly would be a waste of the company's time and money. Ultimately, the team found that, by making some common-sense process changes, they could reduce variability considerably without spending much money. For example, the team discovered that the automatic chuck lock on some machine tools was not locking tightly enough, causing process variability. Therefore, the operators were instructed to lock the chuck by hand, reducing variability. Due to the efforts of the SPC team, the processes had become stable enough to proceed with precision assembly.

The dinosaurs could argue with the changes, but could not argue with the team's SPC data. As a result of the team's efforts in reducing variability, the operators could now concentrate on manufacturing processes that could be held within tenths of thousandths of an inch and produce parts that met their nominal dimensions, rather than merely worrying about getting within (+/-) 0.030".

The shift to precision assembly has also meant a shift in quality metrics to SPC data. A previous program measured quality per direct labor hour (scrap, rework, and defects / labor hour). These type of metrics are not as specific as SPC data.

The company combined SPC with the key characteristics provided by its customer. A product's key characteristic is a design attribute where variation has the most adverse effect. An example of a key characteristic is a critical dimension that must be maintained within a tight tolerance to ensure the fit of one subassembly to another. The customer determined the key characteristics after analyzing component fit and variability stackup, and specified these characteristics on the print. The company takes the customer's key characteristics and finds which upstream processing characteristics should be monitored to ensure that the key characteristics are satisfied. Each process might have several dimensions that must be consistently met to maintain the higher level key characteristic. Therefore, key characteristics help the company identify which critical dimensions need to be monitored using SPC, and which dimensions do not.

The customer has certified the company to implement sampling plans on certain end-item inspections where the process is in control and capable. The process capability index is used to measure the product dimension variability and compare it to the process specifications. A barely capable process (Cpk of at least 1.0) will produce 2,700 defective parts per million. The product studied in this case held a Cpk of up to 1.65 for the (+/-) 0.030 detail locations.

Phase 4.2 Improve process quality:

Departmental work group teams empower the employees to make decisions and solve the department's problems. At first, management found it difficult to empower the employees, but then conceded that no one knows as much about the jobs in the department, or can impact the improvement efforts as much as the workers themselves. Teams are organized around a process, or a product, or both. The team members get 20 hours in team training, and all team members are elected (but are typically the employees in a work area). The teams have appointed facilitators to help run meetings, so managers do not need to attend meetings, but often do anyway. Members of the support organizations (engineering, production control, etc.) are "on call" whenever needed, but do not regularly attend the work group meetings.

Work group meetings are typically held every 1-2 weeks to update outstanding quality concerns, and brainstorm and use fishbone diagrams to recommend action items for themselves or Quality Control to pursue. Informal department meetings are held an average of 2-3 times per week (as needed) to discuss problems. These meetings last approximately 15 minutes and are held in the production area.

Some of the work group teams have had considerable success. Because of proactive attempts at continuous improvement by the work teams in the fabrication area, there were only 8 failures of the first 3,000 products shipped. This is a very low number when one considers that the product's process was new to the area and to the employees involved. SPC data was also used to support processing changes that reduced scrap material.

Phase 4.3 Increase process flexibility:

The company has improved its flexibility in this product area compared to an earlier program. Now a program with 86 percent more variations to it product can produce these products with no tools. In fact any of five locations can assemble all the produce variations. In the past each product variation needed its own set of dedicated tools.

There are also other benefits that accrue with reduced numbers of tools. Many of these benefits can be characterized by reduced storage requirements, elimination of handling equipment and reduced or elimination of tool maintenance.

Phase 4.4 Increase process speed:

As a result of the process improvement efforts a reduction of approximately 64 percent was achieved in actual assembly time comparing performance to the older product. Much of this improvement resulted from the simplified assembly process. The fact that parts consistently fit into precisely located holes allowed this product to be assembled without tools. Removing the necessity to use tools has speeded up the whole assembly process.

Appendix H - Case Study Number Eight

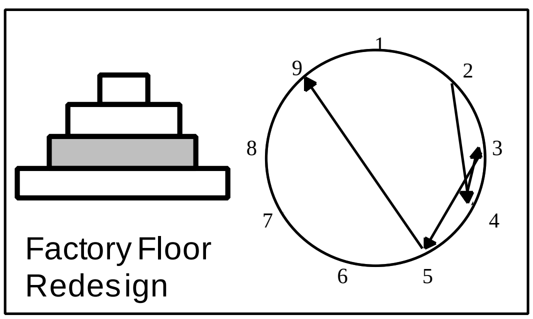
Introduction

This case study is of a major defense company in the airframe industry. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. A major commercial aircraft company, in an effort to reduce both the cost and lead time for the production of its commercial aircraft, was restructured into "responsibility centers". Each center had the responsibility for the design and manufacture of a group of products. The first of these centers, the Door Responsibility Center (DRC), is the subject of this case study.

This case was chosen to be included in the study because the it pertained to the aircraft industry and analyzed how the company could save 50 percent of their assembly costs and increase their throughput by 40 percent.

Total Transition Implementation Sequence

Following is a description of the implementation sequence proposed in this case study and it's comparison to the hypothesized Lean Implementation Model. Appendix H Figure 1 shows the process or sequence proposed. Each box in the diagram represents a roughly chronological stage of lean implementation. In this case study only one implementation phase was observed.



Appendix H Figure 1: Case Study Eight Implementation Sequence

Stage One

Implementing Phase 2 - Factory Flow Redesign

Phase 2.2 Group product into families:

Parts were first grouped into families depending on the material characteristics and production rates. There are 170 stop fittings in the door. Out of the 170 parts, there are 142 unique part numbers. All 142 stop-fittings are used on the two major product doors produced by the DRC. In the first trial to form a group, all the 142 parts were made into the same family. More exhaustive study decreased the group from 142 to 108. The rest of the parts were shifted to another line.

Phase 2.4 Design process layout and simulate flow:

Equipment was selected in order to design the most efficient process. With the selection of the equipment the cell's minimum cycle time was determined and compared with the demand in order to find out if the cell had sufficiently capacity. A U shaped layout was used. The capacity requirement was determined by historical demand. All the machines were placed one next to the other so that the processing of the stop-fitting would follow a continuous flow.

Phase 2.3 Standardize processes:

Not only were the processes standardized, but also the design requirements of the stop-fitting were standardized. A standard material was selected in order to produce all the 108 parts within the family. The process was also rationalized to ensure that it was as efficient as possible. Several operations were eliminated as part of the new process design. Those operations which involve transport or packaging for transport could easily be omitted, however, some more significant operations were also be eliminated. For example, raw material suppliers delivered material already cut to the starting shape, thus eliminating the sawing operation at the beginning of the process.

Phase 2.5 Optimize factory flow and cell linkages:

Once the parts were divided into families, the flow in the factory was changed. The machines and operations were arranged to follow the process of all the parts. Not all the parts would go through all the machines. Some parts would skip some of the machines but the parts would always move in one direction.

Phase 2.9 Make product flow visible within the cell:

The process is divided into two sections. In the first section, part fittings go in single piece flow and during the second half of the process, the parts go in "process-door-flow" fashion". This system is still under improvement. The second section cannot use single piece flow due to a constrain in the machines and technology used. New machines are under design in order to be cost-effective, and at the same time can achieve the same quality. For the cell that implemented single piece flow, the supervisor could tell if there were any major discrepancy in the line simply by observation.

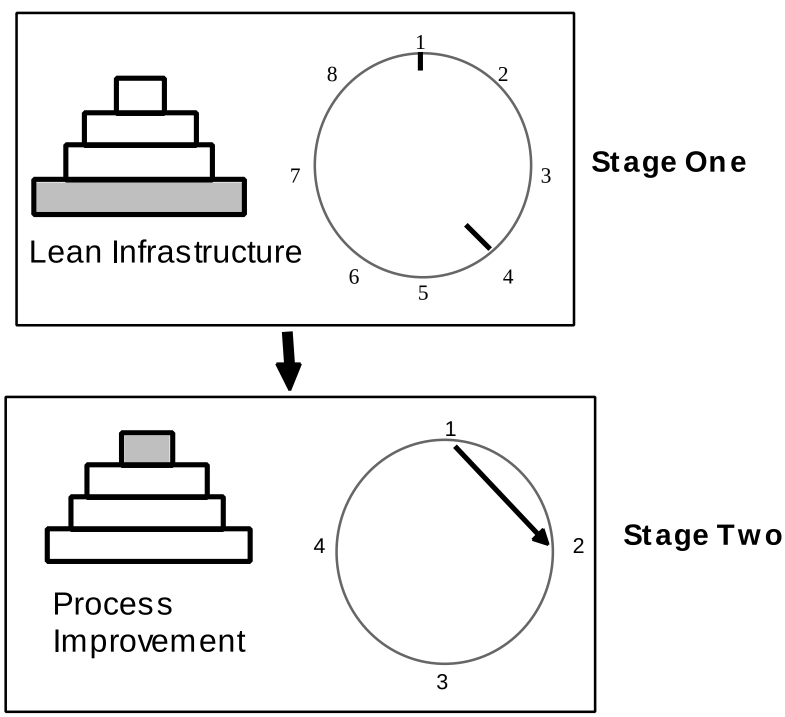
Appendix I - Case Study Number Nine

Introduction

The focus of this case study was to develop and implement a holistic manufacturing improvement methodology which targets process optimization efforts within a polymer sheet operation. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. This case study comes from a thesis written in 1994 by a student from the Leaders for Manufacturing program at MIT.

Total Transition Implementation Sequence

Following is a description of the implementation sequence proposed in this case study and it's comparison to the hypothesized Lean Implementation Model. Appendix I Figure 1 shows the process or sequence proposed. Each box in the diagram represents a roughly chronological stage of lean implementation. In this case study only two implementation phases were observed. The limited application of this case study to the model is most likely due to the focus of the thesis. The thesis concentrated on improving the system using a particular process as the focus of the study.



Appendix I Figure 1: Case Study Number Nine Implementation Sequence

Stage One

Implementing Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop strategy:

This company developed a straightforward strategy. They wanted to reduce process variability and product waste. The strategy can be best achieved through a systematic approach that:

- Provided consistency of operation
- Created an invariant process and product
- Increased quality product throughout
- Worked to minimize operations costs

Phase 1.4 Identify current and needed skills:

From the knowledge and experience activity, fault tree diagrams were completed for the casting process, documenting the relationships between the casting process conditions and the resulting product attributes. These diagrams served to collect the opinions and knowledge of the operators and engineers in one document, highlighting areas for technical discussion, analysis, and documentation.

Stage Two

Implementing Phase 4 - Process Improvement

Phase 4.1 Improve process and operations predictability:

Process improvement activities within the polymer operations were driven by machine teams or by process excellence teams (PETs). Each machine team involved process improvement efforts for their group of machines. The PETs worked on process improvement activities for functional areas such as casting, coating, winding, and conveyance.

While each machine-based team worked on improvement activities for their machines, more cross-trained involvement for sharing and implementing consistent and similar process improvement practices among the various machine teams was needed. While each PET attained near term improvements in their individual functional areas, these teams primarily focused on improving their specific functional areas in the overall production process.

With the implementation of these PETs, this company was able to reduce variability in the production process and make it more predictable by eliminating all the undesired and unplanned down times of the machines involved in the process.

Phase 4.2 Improve process quality:

Nine casting parameters out of the thirty four were found to be important to the casting of polymer sheet. The company made a statistical analysis to determine the important parameters of the process. Once the parameters were determined, experiments were performed to find the correct value of the parameters to maximize the efficiency of the process and improve the quality of the product as a result. In examining the commonality between the parallel activities, it was important to note that the temperature and pressure signals cited by the operations personnel were key to indicating quality problems in the sheet profile which comprised some of the nine casting parameters determined to be important by the multivariate statistical analyses.

The casting parameters selected from the parallel activities was used in a designed screening experiment to determine the casting parameters and conditions critical to product quality polymer sheet.

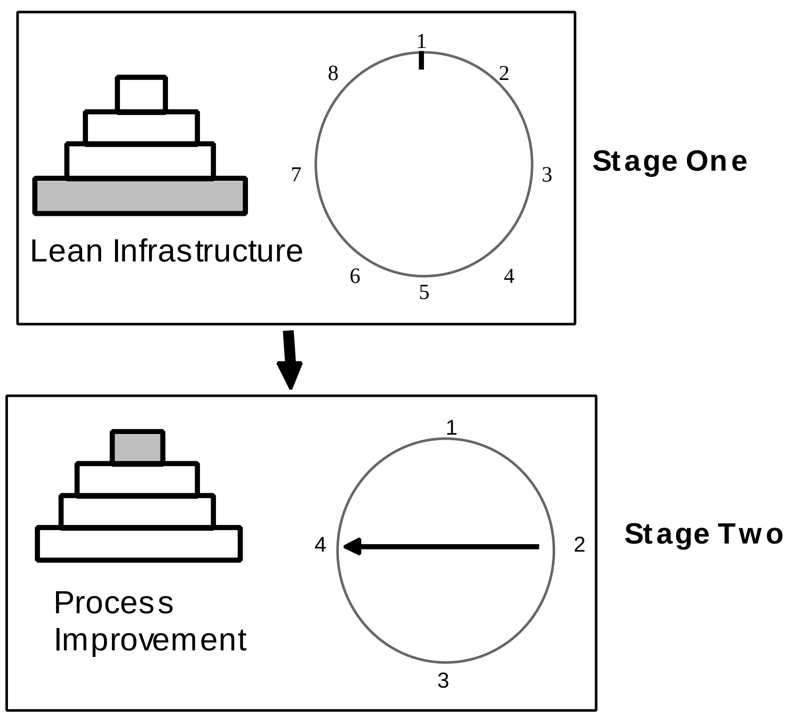
Appendix J - Case Study Number Ten

Introduction

This case study examines the strategy and operational improvements in a manufacturing business. This project focuses on an aluminum can stock plant. A strategic analysis showed that the business unit should pursue a strategy of differentiation through improved quality and delivery performance. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. This case study comes from a thesis written in 1994 by a student from the Leaders for Manufacturing program at MIT.

Total Transition Implementation Sequence

The case study presented in this thesis only applied to phase 1 and phase 4 of the Hypothesized Lean Implementation Model. We found that phase 2 of the model could not be applied in continuous process cases. Therefore, in companies using continuous processes Phases 1, 3, and 4 are the only phases that make sense. Appendix J Figure 1 illustrates the process followed by this company compared to the Hypothesized Lean Implementation Model. This case study is similar to the previous case study and the same phases were used in each case study.



Appendix J Figure 1: Case Study Number Ten Implementation Sequence

Stage One

Implementing Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy:

This company is a fairly focused business. Unlike some of its competitors which manufacture a variety of aluminum products, this company produces only can stock – and primarily end and tab stock. This focused strategy, however, has not provided the plant with a significant advantage over competitors.

Since focus has not provided this company with a competitive advantage, and further streamlining product lines does not appear to be viable, this company understood that it must develop another strategy for obtaining a competitive advantage. The company decided that the desired strategy must be to increase the quality of the product and its delivery performance. By improving both, it would give the company the advantage needed in their business field.

Stage Two

Implementing Phase 4 - Process Improvement

Phase 4.2 Improve process quality:

A key to quality improvement was the use of statistical and analytical methods such as statistical process control (SPC) and design of experiments (DOE). Based upon the current operating practices of the plant, however, implementing SPC or DOE would have been very difficult. The reason for this difficulty was the variability in the way each worker operates the production equipment.

The only way to eliminate special variation was by creating and implementing a system of standard operating procedures (SOPs) for every process and ensuring that workers abided by these rules. The plant workers developed the standard operating procedures, since they were the most familiar with the processes and must live by whatever procedures were created.

Phase 4.4 Increase process speed:

The process speed was improved by optimizing and improving the flowtime. Flowtime here is the length of time it takes to produce a product. Reducing flowtime within a plant is essentially the same as reducing inventory within a plant. There are two types of inventory at this company. First, there are coils in the cooling process. After the hot mill and cold mill, coils are required to cool off for a significant length of time prior to being processed by the subsequent operation. The cooling off period is actually part of the production process.

Second, there are coils that are held as buffers between operations. This company tries to maintain certain inventory targets between each processing center. Both types of inventory can be reduced, albeit in different manners.

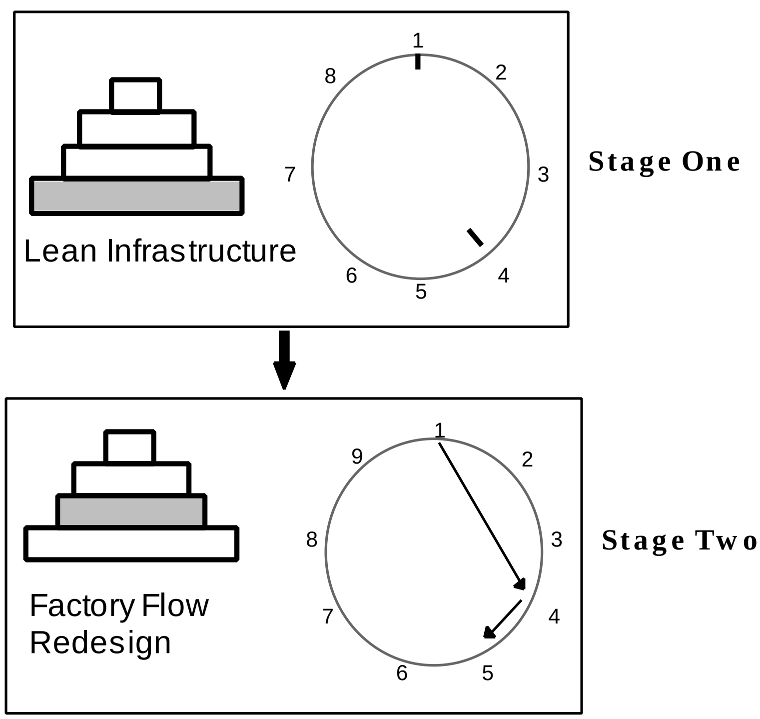
Appendix K - Case Study Number Eleven

Introduction

This case study is of a major toy manufacturer. The product to be studied in this case is the assembly line of a remote controlled race car; however the tool developed in this thesis or the process/methodology used is currently being applied in a major pharmaceutical company. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. This case study comes from a thesis written in 1995 by a student from the Leaders for Manufacturing program at MIT. The main purpose of the thesis was to develop and implement a tool for designing new assembly lines and optimizing existing ones.

Total Transition Implementation Sequence

The case study presented in this thesis only addresses phase one and phase two. This case study was mainly focused in analyzing how to optimize a line by looking at buffer sizing and machine group efficiencies. Also some modeling of different lines was performed in order to determine the most efficient line. The implementation process followed by this company compared to the Hypothesized Lean Implementation Model is shown in Appendix L Figure 1.



Appendix K Figure 1: Case Study Number Eleven Implementation Sequence

Stage One

Implementing Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy:

The goal of this company was primarily to become more competitive improving yields by 20% and to reduce WIP by more than 75%. The strategy used to achieve those goals was to convert the existing manufacturing system into a cellular environment.

Phase 1.4 Identify current and needed skills:

Process optimization techniques in this company were not very well understood. The benefits of small-in-line buffers and their ability to decouple manufacturing systems were not recognized. Operators did not have the knowledge of how to analyze a process or the efficiency of their work. What the company realized was that they were lacking in the necessary skills to analyze and improve their operations. The operators had no idea whether they were doing the right thing or not. Both the operators and the supporting engineers needed to learn about the techniques used to optimize their processes.

Phase 1.6 Breakdown stovepipe mentality:

The manufacturing organization was very skilled technically and had the advantage of a well qualified and very cooperative direct labor force. Over the past ten years, many changes have taken place within this facility. The organization had transitioned from a batch manufacturer to cellular manufacturer and was currently striving to achieve a continuous non-buffered flow. As this organization transitioned from batch to cellular manufacturing, it developed a belief that production buffers are non productive and thus should be eliminated. This belief has been confirmed as production volumes, yields, and customer responsiveness have increased/improved due to the elimination of buffers.

Stage Two

Implementing Phase 2 - Factory Flow Redesign

Phase 2.1 Distribute information:

In order to start the design of the process, individual workstation performance information was obtained. Several methods for obtaining performance data directly from a manufacturing cell exist; however, the most efficient method was electronic collection. After the data collection was completed, the individual workstation ‘mean-time-to-failure’ and mean-time-to-repair’ were evaluated to assure their properties (exponential properties).

Phase 2.4 Design process layout and simulate flow:

The process layout was designed in such a way that the machine location followed the process itself. In the simulations performed, different layouts were studied but the most important aspect was determined to be the buffer size, the buffer location, and the buffer placement.

The machine group’s efficiency was also studied using an algorithm. The goal was to have equal cycle times for all machine groups within a manufacturing cell. By making all machine groups approximately the same, the efficiency of the worst performing machine group is maximized.

Phase 2.5 Optimize factory flow and cell linkages:

Improving the buffers between each operation optimized the flow at this company. Since the product went from one cell to another somewhere in the company, they “linked” the cells by placing an infinite buffer between each cell. No major discussion of this point was presented in the thesis; however the author pointed out that an algorithm was developed to optimize the buffer size.

Appendix L - Case Study Number Twelve

Introduction

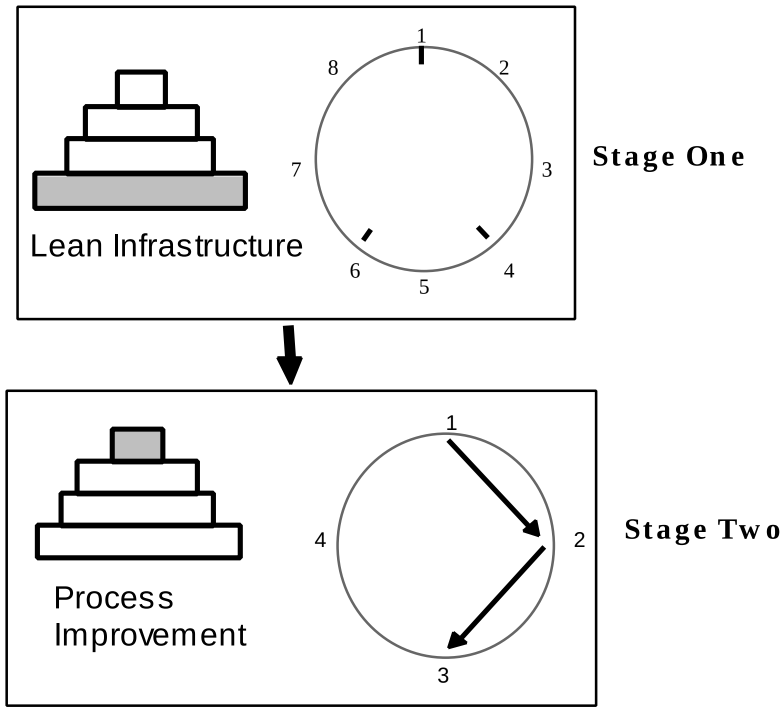
This case study is of a major pharmaceutical company which manufactures solid dosages (tablets) and encapsulated products. This case study was performed prior to the creation of the hypothesized Lean Implementation Model. This case study comes from a thesis written in 1992 by a student from the Leaders for Manufacturing program at MIT.

The main purpose of the thesis was to propose an enhanced framework for systematic manufacturing system improvement. The thesis entailed viewing, attacking and correcting various problems or processes through systematic and planned approaches. After the framework was developed it was implemented in a medical or pharmaceutical company.

Total Transition Implementation Sequence

The proposed framework and case study performed in this thesis shows only two out of the four phases of the hypothesized Lean Implementation Model. The case study touches sections of phase 1 and phase 4. This may be due to the type of product manufactured in this company. However it is noted that this Lean Implementation Model can also be used in other industries that are not discretely manufacturing. Appendix L Figure 1 illustrates the implementation sequence followed.

In stage one, the company started by establishing an environment and structure which recognized the need and importance of process improvement. They also defined the areas for improvement and prioritized these with obtainable goals. After the strategy was developed and they had identified their current and needed skills, they started implementing the ideas into the process. During the second stage, this company only used three practices; however, they achieved most of their goals.



Appendix L Figure 1: Case Study Number Twelve Implementation Sequence

Stage One

Implementing Phase 1 - Lean Infrastructure

Phase 1.1 Identify business issues/goals and develop a strategy

Upper management set a goal to reduce cycle time by 30% and reduce cost by $3M in the coating process of the tablets. To meet this challenge, middle management created two project areas: eliminate 100% inspection and increase yields of product B.

Phase 1.4 Identify current and needed skills

Management in this company studied all the workers in charge of performing the coating process of the tablets. They interviewed and analyzed the skills of not only the direct labor, but also the indirect labor associated with that specific process. Management studied the current skills of those workers and decided which skills were needed in order to perform the operations within the process better. The management also identified the goal of enforcing cross-functional teams on the floor to solve all the problems related with the low yield of the product.

Phase 1.6 Breakdown stovepipe mentality:

Management knew that the workers needed to be empowered in order to keep the processes running. Therefore, a very important goal was to change the mentality so that there would be one worker for each function in the plant. Management decided to change this mentality throughout the entire plant.

Stage Two

Implementing Phase 4 - Process Improvement

Phase 4.1 Improve process and operations predictability:

The cause and analysis chart identified several equipment problems. The first to appear was a pump dispensing problem. Experimental evidence indicated that the pumps were not dispensing the calibrated quantities of fluid. Soon after this problem was identified, operators began experiencing problems maintaining negative air pressure in one of the pans. In the spray arm, the operators also noticed that sometimes the spray rack sagged. All these problems were causing a very unpredictable thickness in the coating of the tablets. There was also unpredictable changeover times when changing from one tablet thickness to other. In this case, the identification of the sources of the unpredictability was tantamount to improving the process.

Phase 4.2 Improve process quality:

The quality of the process was also improved in order to eliminate the 100% inspection. New devices were placed on the line to prevent mistakes from happening. These devises detect the evidence of an applied coating and whether the specified amount of coating was applied. When out of specification conditions were detected, the entire line was stopped until an operator could fix the problem.

Phase 4.3 Increase process flexibility:

Flexibility in this case meant changing from one product to another. The company wanted to use the same line to spray a non-aqueous film coating on tablets. Flexibility was obtained by designing a new controller for the spry arm distance control. The arm was adjusted manually before the new design, a practice that lacked accuracy and consistency.