LEAN VISUAL MANAGEMENT IN AN ERP/MES-CONTROLLED PRODUCTION CELL

By

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Submitted to the MIT Sloan School of Management and the Department of Engineering Systems in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
AND
Master of Science in Engineering Systems

In conjunction with the Leaders For Manufacturing Program at the
**Massachusetts Institute of Technology**
June 2009

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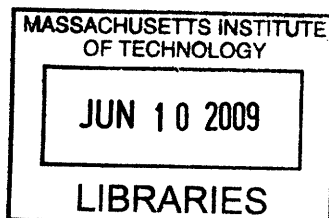
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Master of Science in Engineering Systems Design

ABSTRACT

As a company grows, more and more effort is needed to control and coordinate operations. Typically, this is accomplished through an evolving collection of systems and processes, such as an Enterprise Resource Planning (ERP) system, but such systems also influence how a company does business, reviews performance, and communicates results. Manufacturing Execution Systems (MES) are often used in conjunction with ERP systems to streamline and enable actual manufacturing processes. A third type of system, the visual management system, is used to take production out of the closed, computerized realm and make it open, intuitive, and efficient.

Visual Management, as a lean concept, can be a simple and effective means to efficiently regulate inventory levels and production activities. However, when visual management systems are to be embedded within a broader ERP/MES system, certain conditions and support systems are requisite, the absence of which will render the visual management system ineffective, at best, or destructive, at worst. Furthermore, there are fundamental issues around implementing visual management, be it high-tech or low-tech.

This thesis will describe a case study of the process to manage the design and implementation of a visual management system, while addressing various stakeholders' needs and refined business objectives. Theories and frameworks of Enterprise Architecting and Change Management are utilized to analyze which functions the visual management system should perform and how to achieve operator buy-in.

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ACKNOWLEDGMENTS

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GLOSSARY

5S: The five steps used to organize and standardize the workplace all start with "s" in Japanese (seiri, seiton, seison, seiketsu, and shitsuke), loosely translated to sort, set in order, shine, standardize, and sustain

Batch size reduction: The goal of reaching a batch size of one. If one-piece flow is not appropriate or possible, reduce the batch size to the smallest t number possible.

Cellular flow: Maximize value added content and minimize waste by physically linking manual and machine process steps in the most efficient combination. Waste associated with batch, queue and waiting can be reduced in both manufacturing and service organizations.

ERP: Acronym for Enterprise Resource Planning. ERP systems are integrated Information Technology (IT) systems which combine and coordinate transactions for such business functions as finance, sales and marketing, operations and logistics, human resources, and materials management.

Lean Culture Change Initiative (LCCI): An Operations-focused initiative, modeled after the Toyota Production System (TPS), designed to cultivate lean principles and improve supply chain output to world class levels which was.

MES: Acronym for Manufacturing Execution System; a networked, integrated, and computerized system which enables various methods, processes, and tools to accomplish production.

Point of Use Storage: The storage of materials, parts, tools, information, work standards, and procedures where they are needed. Provide only as much space as necessary at each workstation so overproduction, excess inventory, and motion and transportation wastes are minimized.

Pull/kanban: A production practice in which cascading production and delivery instructions move upstream, triggering the upstream supplier to start production only when downstream customer signals a need. In a nonmanufacturing organization, a kanban system can be set up with vendors to deliver supplies as needed.

Quality at the source: Where each employee carries out his or her own inspection, review, and process control. This helps ensure the product passed on is of acceptable quality.

Quick changeover: The ability to rapidly (within minutes) change a machine's tooling and fixtures so smaller batches of multiple products can be run on the same equipment. In a non manufacturing organization, this means, for example being able to quickly change from processing one file, order, or claim to another or being able to quickly get an operating room ready for the next surgery.

Standard work: Ensuring all tasks are performed according to prescribed and standardized methods that focus on ergonomics and safety. Standard work helps achieve good quality, predictability, and set cycle times.

Streamlined layout: Designing the facility's layout according to optimum operational sequence. Emphasize line of sight interaction in internal supplier-customer hand-offs.

Total Productive Maintenance (TPM): An equipment maintenance strategy to maximize equipment effectiveness, by enhancingequipment availability (uptime), performance (throughput), and quality (first pass yield).

Value Stream Mapping (VSM): The process of mapping the set of actions required to take raw materials to finished goods according to customer demand, including both information management and physical transformation tasks.

Visual Management: Keeping all required items, parts, files, information, processing activities, and indicators in view so everyone involved can understand the status of the system at a glance.

Waste of defects and correction: Quality problems that necessitate rework, repair, or replacement. In nonmanufacturing organizations, incomplete or inaccurate information can lead to this type of waste.

Waste of inventory: Carrying more materials, parts, or information than necessary at any given time. Having to process in batches is one symptom of excess inventory.

Waste of motion: Any extra movement by people that does not add value.

Waste of over processing: Effort that adds no value to the product or service from the customer's viewpoint. Redundant reviews and approvals also constitute over processing waste.

Waste of overproduction: Making or processing more, earlier, or faster than required by the next process.

Waste of people: Not fully tapping into an employee's experience, knowledge, creativity, or skills.

Waste of transportation: Excess or unnecessary movement of parts or information.

Waste of waiting: Idle time while waiting for things such as manpower, materials, information, machinery or equipment, inspection, or sign-offs.

INTRODUCTION

1 Introduction

1.1 General Issue

Businesses, both public and private, must compete to survive. In many industries, in the short-term, the market is growing only slightly, so that competitors in the market experience extreme pressure to cut costs and improve efficiency. For many successful companies, the ability to have comparably lower operating costs is a strategic advantage, as in emerging Japanese companies of the middle 20th century. The companies founded a new school of thought, called Lean Production, which focused on cutting out the waste, or the fat, of the business and being able to maintain profit margins while underselling, per unit of product performance, their competitors.

One of the ways lean companies have become competitive is through the practice of Visual Management, the use of simple, visual cues and accompanying processes to regulate inventory levels and production activities, in contrast to an emerging trend toward large data base-enabled systems and integrated IT solutions. As companies merge, acquire, or otherwise grow, the choice of going low-tech or high-tech will be increasingly important and will have far-reaching implications on a company's strategy, profitability, and overall competitiveness.

1.2 Specific Issue

Every company will need to make strategic decisions for the company's distinct blend of high-tech and low-tech suite of systems and processes, but not only when the system is designed, purchased, set up, and brought live. Systems and processes should be periodically brought into question, for example whenever a business-related technology or production process matures,

competitors change policy or react, or the competitive landscape changes. Under what conditions would it be best to use a simple, pull system, when should full confidence be invested in a large-scale ERP, or what of a combination of both? Furthermore, when an ERP is necessary to fulfill a company's overarching strategy in terms of supply-chain cohesiveness and coordination, but production is simple enough to be executed using visual methods, what should the boundaries and interfaces be to allow the systems to coexist?

1.3 Hypothesis

Visual Management, as a lean concept, can be a simple, intuitive, and effective means to efficiently regulate inventory levels and production activities. However, when visual management systems are to be embedded within a broader ERP/MES system, certain conditions and support systems are requisite, the absence of which will render the visual management system ineffective, at best, or counterproductive, at worst. Furthermore, there are fundamental issues around implementing visual management, be it high-tech or low-tech.

1.4 Thesis Organization

Chapter 1: Justification for the research project is provided, including general and specific issues to be discussed and the hypothesis to be supported.

Chapter 2: Disguised company and market context is provided, including product nature and organizational structure. In addition, an underlying Lean Culture Change Initiative is discussed in as much as it relates to the research topic.

Chapter 3: Different aspects which touch on the research question are presented, such as lean principles and Visual Management theory, are explored in the Literature Review. Other frameworks used both in designing and implementing a visual management system, such as theories in Change

Management and Enterprise Architecting. Next, both ERP and MES systems are explored in detail. Lastly, a number of other visual management solutions are covered through past Leaders For Manufacturing theses.

Chapter 4: The initial state of planning and production execution is explored. Tenets of the initial visual management system are discussed. Next, three different visual management systems are built in series to meet company needs. Strengths, weaknesses, and implementation issues of each are addressed.

Chapter 5: Conclusions are drawn from the research project's outcome. Recommendations are given for leaders tasked with designing and implementing visual management systems. Lastly, recommendations for future research are discussed.

2 Research Site Overview

Due to the nature of the business, its products, suppliers, and customers, it was deemed prudent to disguise all company and product information. As premise, this thesis holds that a visual management system is installed to meet specific operational needs, and it would be difficult to touch on anything of substance without possibly exposing the author or the company to undue risk. Therefore, "ABSCompany" was created, and the following information was viewed as relevant to understand the environment in which the visual management system was created.

2.1 Company

The research and ensuing case studies were performed over a seven month period at a production facility of a large, multinational, multi-business unit, technology and manufacturing company in the Southeastern United States. Business units are strategically diversified across the aerospace, integrated electronic solutions, materials, and broader transportation supplies industries, serving government, defense, and commercial markets worldwide. 2007 Annual revenues for the site were in the $400M range from a workforce of 1000 engineering, 550 supply chain, and 100 support employees.

2.2 Products

Products from this site are high cost, breadbox-sized, electrical devices used for military and commercial applications. Product architecture consisted of an internal chassis to which various subassemblies and circuit cards were installed, encased in a protective, metal housing. Product demand is characterized as low volume and high mix. Product life cycles can be greater than 20 years, owing to the useful life of the product and long life of the parent product's installed base.

Subassemblies and circuit cards are produced both internally on site, internally within the company but at other locations across the United States, and sourced externally from the continental US.

2.3 Organizational Structure

The company is organized as a matrix according to functions and programs. Production is carried out in the supply chain organization, comprised of Sourcing, Quality, Advanced Production Manufacturing (low-rate new product production), Materials Management, Shipping/Receiving, and "Integrated Product Teams" (IPT), basically a grouping of similar products which can be traced back to the engineering program from which they originated. IPT's, in turn, consist of a manager, Production Planner(s), Master Scheduler(s), assembly operators, Team Lead, and support personnel such as manufacturing, process, and quality engineers.

2.4 Amidst a Lean Culture Change Initiative

Underway within the company were a number of initiatives aimed at improving operating efficiencies, lowering costs, and shortening product design and production cycles. The first, and probably the most important, is an Operations-focused initiative to cultivate lean principles and improve supply chain output to world class levels. Modeled after the Toyota Production system, the culture-focused initiative had elements of continuous improvement, employee empowerment and responsibility, visual management, standard work, built-in quality, team-driven rapid problem solving, and smooth production flow.

At the same time, the holistic strategy of the company was to reconcile the long list (in the 1000's) of legacy operating, planning, and other business software to a short list of approved software running on a common ERP-based backbone. Each site had as goal to reconcile its needs with the abilities of a customized software solution to be implemented in the near future.

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Taken together, site leadership realized the need to examine the suite of IT software solutions and management processes to determine what the future state system should look like. Both the consolidated software solution and the operating system solution would dictate production activities. Since redundancy is usually a waste to be minimized, a balance had to be struck, and boundaries had to be drawn.

3 Literature Review

The debate between increasingly comprehensive and complex IT systems and simple, lean solutions has been common ever since Japanese companies began to outperform competing western companies on dimensions of cost, quality, responsiveness, and time to market. Research on the trend concluded that the Japanese systems and processes, as a part of the overall enterprise architecture, were more efficient at managing production activities. This literature review will first explore the essence of "Lean" and one of its tenets, Visual Management. Next, Visual Management will be discussed in context of Change Management and Enterprise Architecting theories. Then, the functionality, capabilities, and limitations of ERP and MES systems will be treated. Lastly, the methodology of other companies will be examined, namely those who have solved the problem of interfacing ERP/MES solutions with appropriate lean visual management systems.

3.1 Origin of Lean

The Lean movement has its roots in the efforts of Japanese firms to rebuild and attain competitiveness in the wake of World War II. By the 1980's, an awareness of this competitive advantage was beginning to be recognized, which launched an academic and industry frenzy to study, understand, and codify the system. In one book, "The Machine That Changed the World" by James Womack, Daniel Jones, and Daniel Roos, the term "lean production" was coined. Published in 1990, the book discusses the results of a 5-year study of Toyota and other auto manufacturers, to discover the differences between Toyota's production strategy and traditional, western mass production (Womack J. P., 1990). The ideas of lean manufacturing were further explored in case study form in the authors' subsequent book, "Lean thinking" (Womack J. P., 1996)

3.1.1 Lean Basics

Central to lean principles is the identification and reduction of waste. Eight sources of waste have been identified, namely overproduction, inventory, defects and correction, over processing, waiting, people, motion, and transportation (see glossary for definitions). One especially valuable tool developed by lean practitioners is called Value Stream Mapping (VSM), which is used to identify and eliminate wasteful operations. In VSM all actions and information flows used to make a product or perform a service are captured pictorially and reduced to streamline value-adding and minimize non-value-adding activities. (Alukal, 2006)

Besides VSM, one key tenet of Lean is the "pull" production system, commonly referred to as a kanban system for the "kanban" cards or signals passed or communicated up the value chain to initiate production activities. A pull production system is one in which real demand, in the form of a purchase or sales order, initiates, or "pulls", production activities. In a "push" system, on the other hand, forecast demand initiates production activities. "Pushed" goods are riskier, because product is produced ahead in time of real demand, which results in finished goods waiting to be distributed and sold, whereas "pulled" products have a customer waiting. The kanban system, long heralded as the epitome of the lean manufacturing movement, is explained to also be an extension of visual management, because it signals what should be made and by whom.

While the virtues of the kanban system are generally associated with as a means of controlling material flows, it has also been shown that kanban, by its just-in-time nature, can facilitate problem solving, process improvement, and learning as precursors to outstanding performance. Steve Spear maintains that a kanban is an embedded test, that "problem solving done close in time, place, and person to problem occurrences capitalize upon the ability of the embedded tests to indicate when

assumptions in the work design are incorrect. This simultaneously builds process knowledge and capability." (Spear, 2002).

Another building block of lean, and starting point for Visual Management, is the practice of "5S". The five S's refer to the Japanese "seiri, seiton, seison, seiketsu, and shitsuke", which loosely translate to "sort, set in order, shine, standardize, and sustain". 5S helps a production area, be it a manufacturing facility or office environment, sustain a level of orderliness and standardization which helps wastes, defects, and abnormalities become more apparent.

In addition to VSM, 5S, and Pull/kanban, there are many other components that have grown out of the lean movement and become more or less common knowledge. A general list of lean principles is shown in Table 1. While it is beyond the scope of this paper to address each one in detail, many are referred to in the coming pages, so definitions are available in the glossary. (Alukal, 2006)

Table 1: List of lean principles

Value Stream Mapping	5S
Visual Management	Quick changeover
Streamlined layout	Batch size reduction (single piece flow)
Point-of-use storage	Pull/kanban system
Standard work	Cellular flow
Quality at the source	Total productive maintenance

3.1.2 Visual Management

The theory of Visual Management is really quite simple, namely the use of visual cues to prompt some logical action. For instance, a sink of dirty dishes prompts a dish washing process, or a nearly empty jug of milk prompts a trip to the grocery store. However, using visual cues as a way

to regulate, prioritize, and coordinate factory-scale supply chain activities is a more recent innovation of 70 years.

In a trade journal of circuit board manufacturers, Marty Neese, Corporate officer and Executive Vice President of operations at Solectron, discusses using a visual factory to drive lean. Neese points out that the underlying concept behind the "visual factory" is to communicate unambiguous information to shop floors to enable them to do their jobs. Visual communication is clearer than verbal or written instruction, because it goes across language and cultural differences. "Through the use of colored tape, blinking lights, full or empty storage locations, progressive-step production boards, etc., the state of any value-adding facility can be quickly assessed. Sequencing boards provide customer focus teams, operators and managers with a view of the current shop floor status, including information flow, materials availability, readiness and abnormalities." (Neese, 2007)

Another aspect of visual management is the production andon, which simply means to signal an abnormal or undesired condition. In early Japanese assembly lines, if an operator recognized he was falling behind and was not going to finish his work in the allotted time, he pulled an andon chord which actuated a switch and lighted a bulb. This prompted immediate action from the line supervisor to 1) help the operator complete the operation in time and, more importantly, 2) to help the operator figure out why he was late and how to prevent the defect at that station in all subsequent operations (Neese, 2007). Thus, the term "andon" is often used synonymously with the real-time escalation process for a slowed or stopped production line.

It has already been discussed how visually displayed cues can help schedule production and discover defects or abnormalities in current production, yet one of the most common uses of Visual Management is to communicate the metrics, goals, and objectives of the viewing audience

(Dossenbach, 2006). Posted metrics, which could range from the number of operator safety incidences to production cell efficiency to factory revenues or costs, should be informative yet simple to understand. Since the posting of metrics and goals is not a tangible part of the finished product or service, from the standpoint of the customer, it adds no direct value to the product or service. This fact requires that the metrics and goals be easy to generate, update, and maintain. Further, the postings are most effective when displayed in a place of prominence where there is no clutter.

3.2 Visual Management and Change Management

Implementing a visual management system shares the challenges of any new initiative, namely gaining acceptance over the status quo. The new way must not only be on par with status quo, it must also be significantly better, in order to overcome resistance to fixing something which "isn't broken". To be fair, many management teams roll out a seemingly unending number of productivity, quality, customer satisfaction, and safety improvement programs, and the front-line employee levels usually bears the brunt of these, yet companies must change and adapt to remain competitive in a changing marketplace.

In her book, Janice Klein maintains that true change comes from within an organization, from those who are acquainted with the challenges and opportunities within the firm's culture and daily operations. Insiders may be entrenched, comfortable, and insensitive to possible performance gaps, and outsiders, such as consultants, have trouble gaining followership. Certain people, "outsiders on the inside" are key to driving innovation, adaptation, and real change, because they have maintained outsider perspectives while being able to leverage insider relationships to cause others to question

the status quo.   The three conditions of people power, approach, and organizational support infrastructure are requisite to create real change.

Change occurs when an insider indentifies a specific challenge as an opportunity to pull in outside perspectives, and the organization encourages adoption through an open culture. Lasting change cannot be pushed on others; Pulled change occurs when end-users recognize there is a performance gap between current knowledge base or approach and what is needed to achieve strategic objectives.

There are opportunities to pull in new ideas for both macro and micro challenges which combine to contribute to the organization's strategy. Management must facilitate alignment between macro and micro "pulls". Senior leaders must identify and clearly articulate key strategic thrusts that will respond to macro challenges. Middle managers must ensure that resources utilized to address micro pulls are aligned with the organization's strategy. Middle managers are best situated to match outsider perspectives and strategic needs by linking grassroots outsider-insiders to jobs where they can use their knowledge and skills to pull in new ideas or concepts. (Klein, 2004)

Furthermore, J. P. Kotter suggests that empowering broad-based action, in particular encouraging risk taking and non-traditional ideas, activities, and actions, is key to creating change. The guiding principle of any successful change effort is the involvement and empowerment of employees in the facilitation and leadership of change in the middle of the organization. A summary of his eight-stage Change Management process is found below in Table 2: Kotter's Eight-Stage Process of Creating Major Change

1	Establishing a sense of urgency
2	Creating the guiding coalition
3	Developing a vision and strategy
4	Communicating the change vision
5	Empowering broad-based action
6	Generating short-term wins
7	Consolidating gains and producing more change
8	Anchoring new approaches in the culture.

. (Kotter, 1996)

Table 2: Kotter's Eight-Stage Process of Creating Major Change

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7	Consolidating gains and producing more change
8	Anchoring new approaches in the culture.

In short, change cannot be pushed, but the need to change has to be recognized and wanted by those who will be most affected by it. Instead of command and control, a model of influence,

engagement, and alignment is most effective, as exemplified in the following statement by Antoine de Saint-Exupery:

"If you want to build a ship, don't drum up people together to collect wood and don't assign them tasks and work, but rather teach them to long for the endless immensity of the sea."

3.3 Visual Management and Enterprise Architecting

The need to implement a visual management system, or any other type of improvement program, must originate in some perceived need or short fall. Sources for this need could be company strategy, industry best practices, or a competitive industrial landscape.

Visual Management was only a part of the larger Lean Culture Change Initiative mentioned in section 2.4. The cultural change initiative was consistent with the definition of Enterprise Transformation as set forth in William B. Rouse's paper, in which he discusses different classifications or degrees of change, differentiated by degree of Enterprise Transformation. "Enterprise Transformation is driven by experienced and/or anticipated value deficiencies that result in significantly redesigned and/or new work processes as determined by management's decision making abilities, limitations, and inclinations, all in the context of the social networks of management in particular and the enterprise in general." (Rouse, 2005)

Enterprise Transformation requires a more holistic view of Change Management. Enterprises are complex, integrated systems of processes, organizations, information, and supporting technologies, but they really only exist to produce value for stakeholders. Enterprise Transformation comes after Enterprise Architecting, which is the process of engineering, structuring, and managing the different organizations, systems, and processes to achieve the enterprise's value-adding goal. On a more practical level, it is deciding what functions or tasks

should be performed by whom, and creating a system which will coordinate the timely execution of primary and auxiliary functions. Linkages and interfaces between system components need to be aligned to enterprise values.

Visual management is a form of Information Technology. Under normal situations, Information Technology systems act as enablers to an enterprise, but enterprises usually have to adapt processes and products to meet IT needs. In fact, even Enterprise Architecting has taken an IT-centric stance because of this fact. The abilities and constraints of individual subsystems will influence what functions and tasks must be performed by others, some of which may be classified as non-essential non-value-add.

Nightingale and Rhodes define Enterprise Architecting as the "application of holistic thinking to design, evaluate, and select a preferred structure for a future state enterprise to realize its value proposition and desired behaviors." To aid in the process of Enterprise Architecting, they suggest the use of an eight-view framework (strategy, policy, process, product, service, knowledge, information, and organization). This framework allows an enterprise's architecture to be simplified into a useful and comparable set of perspectives. Enterprise Architecting looks not only at the 'as is' and the 'future state', but the 'could be' states of the transforming enterprise. Decisions are made between alternative 'could be' states in context of factors such as the business model, technology, purpose, culture, and strategy. (Nightingale, 2004)

3.4 System and Process distinction

Defining a "system" would also be helpful, as general agreement on what constitutes a system, a process, and the emerging classification of "system of systems" is lacking. Broadly defined, a system is a group of interacting, interrelated, or interdependent elements forming a complex whole.

However, the word "system" is often used mistakenly interchangeably with "System", with a capital S, which is a functionally related group of elements, especially a network of related computer software, hardware, and data transmission devices. An operational process, on the other hand, is a series of actions, changes, or functions bringing about a result (http://www.thefreedictionary.com/system, 2009).

Furthermore, a "system of systems", as defined by Mark W. Maier, is not a distinction used solely for the complexity of its components or geographic distribution. Instead, it is one in which the individual systems must have both "Operational and Managerial Independence" of its components. "A system should be termed a "system of systems" when (1) its components fulfilled valid purposes in their own right and continued to operate to fulfill those purpose is disassembled from the overall system, and (2) the components systems are managed (at least in part) for their own purposes rather than the purposes of the whole." (Maier, 1999)

A visual management system therefore, can actually be comprised a system of systems, some of which are processes, necessarily carried out by direct human actions, and the other through the more traditional IT-enabled system.

3.5 ERP Functionality, Capabilities, and Limitations

Enterprise Resource Planning (ERP) systems have become nearly commonplace in most large corporations. Their popularity was somewhat bolstered by the Y2K scare of 2000 and the need to consolidate legacy software systems which might break down as a result. Furthermore, as corporations grow through mergers and acquisition, the need to consolidate incompatible systems has also provided a push to implement ERP-type information technology. ERP's are the most prevalent form of IT employed to coordinate extended value chain activities.

Beyond software compatibility and consolidation reasons, there are many other reasons which make ERP systems attractive. Most important is the seamless integration of finance, sales and marketing, operations and logistics, human resources, and materials management. This linking mechanism enables data visibility and process standardization across the entire business. Other reported benefits are lower inventories, shorter delivery cycles, shorter financial close cycles, and a 5-20% return on investment. Lastly, the integrated platform enables global operations and e-commerce abilities.

An ERP system, as a part of broader IT, is just one among a long list of enablers (people, knowledge, suppliers). Thus far, no single software has been found to meet the needs of any enterprise, much less all of them. For this reason, ERP systems are modular in architecture such that various modules and 3rd party "bolt-on" software can be bundled together to meet the custom needs of a given enterprise. Still, system compatibility is the biggest challenge in this regard.

However, ERP systems are not without limitations. They are complex, and implementation of one can be time-consuming, difficult, and expensive. Even beyond the average 12 month drop in productivity which accompanies the best-planned implementations, the investment may take years to recover fully, and there is no guarantee of a successful outcome. On a more practical level, the need to make a single system which can handle any business need has led to a very complex, multi-layer architecture, making user navigation tedious and time-consuming. Lastly, extensive training is required to understand and use an ERP system. (Mabert, Soni, & Venkataramanan, May-June 2001)

Another aspect which an enterprise must consider is the effect an ERP will have on its existing strategy, systems, and processes. An ERP will tend to impose its own logic on the company's strategy, organization, and culture. It pushes toward full integration and generalized processes, when partial segregation or slightly customized processes might be better strategy. While this can be

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overcome with expensive, custom bolt-on software packages, cost pressures typically just force the enterprise to suffer a loss of potential competitive advantage. (Davenport, 1998)

3.6 MES Functionality, Capabilities, and Limitations

Another software domain often employed in conjunction with an ERP's is the Manufacturing Execution System (MES). While the dividing lines between ERP and MES functionality continue to blur as providers of both add complete enterprise functionality, current MES systems do generally contain any of the following 11 modules shown in Table 3, as defined by the Manufacturing Execution Systems Association (MESA). (Manufacturing Execution Systems Association, 1997)

For an MES to be effective, however, it must usually be installed in conjunction with an ERP or other manufacturing information system. In fact, most of the MES functionality is derived from this underlying database backbone. (Sargeant, 2003)

Table 3: MES functionality as defined by MESA

Resource Allocation and Status	Manages resources including machines, tools, labor skills, documents and other materials.
Operation/Detail Scheduling	Sequences and times activities for optimized plant performance based on finite capacities of the resources and attributes of specific production units.
Dispatching production unit	Manages the flow of production units in the form of jobs, orders, batches, lots and work orders by giving commands to send materials or orders to parts of the plant to begin a process or step.
Document control	Manages and distributes records or forms on products, processes, designs, or orders.
Data Collection	Monitors, gathers, and organizes data about processes, materials, and operations from people, machines, or controls.
Labor Management	Monitors the status of operations personnel based on qualifications, work patterns and business needs.
Quality Management	Records, tracks, and analyzes the performance of product parameters to engineering specifications.
Process Management	Directs the flow of work in the plant based on planned and actual production activities.
Maintenance Management	Coordinates activities that allow plant equipment to function continuously.
Product Tracking and Geneology	Monitors the progress of units, batches, or lots of output to create a full product history.
Performance Analysis	Evaluates actual plant performance against goals and historical performance.

3.7 Information Technology as an Enabler to Lean

During a research internship at Raytheon, Charalambos J. Antoniou examined the effectiveness of visual analytics in a program/product development environment, specifically whether Information Technology could act as an enabler to lean. Raytheon uses a custom-built software called Virtual Business System (VBS) to compile and calculate production area and site-wide metrics and display them on a continuously refreshing, multiple-screen dashboard on flat-panel screens throughout the site. Table 4 below contains a sample of the key metrics reported. This form of a visual management system automatically draws its data from the site's ERP and MES systems and

calculates the metrics, meaning the variable, or ongoing, costs to maintain the VBS system are negligible.

Table 4: Metrics displayed by VBS (Antoniou, 2008)

Past due to plan
Current demand
Number kitted parts awaiting processing
Work In Process inventory
Average monthly production by group (past 6 months)
Average cycle time by part number (past 6 months)
Cycle time standard deviation

It was shown that the VBS system enabled a lean environment by providing lean data and promoting lean thinking. While displaying metrics does not make a production facility lean, if a lean culture or environment already exists, the easy availability of credible data enables management and production personnel alike to make better strategic, operational, and tactical decisions. Specifically, VBS created the following value for the enterprise: (Antoniou, 2008)

- Performance data was used to identify and solve problems in real time before damage is done.

- No extra work was required to create or view critical data – data was automatically generated.

- Data actively promotes accountability – operators felt ownership of their area's performance.

- Actionable data was continuously delivered to people who can improve performance.

- Timely data was used to make decisions and influence behavior.

3.8 Performance Metrics and Visual Analytics

Daniel Wolbert researched how the use of visual metrics improved operations at a manufacturing facility on several fronts. First, visibility into receiving inspection backlog prompted smoother and timelier throughput of inspected parts. This contributed to more current snapshot of first pass yield, which in turn, enabled the process to be kept in control more regularly. Similarly, downstream processes had more visibility into the now-smoother arrival of already-inspected parts. Lastly, more rapid feedback allowed for quicker continuous improvement cycles.

In order for a metric to produce value-add behavior, the metrics need to be aligned with company's and site's strategic goals, but even then, careful consideration must be made that the desired performance is captured in the metric and not susceptible to gaming. Since strategy is different at different levels, so too must metrics be tailor-made to drive the right behavior. Also very important is that the metric be structured in such a way that those for whom the metric is intended have the power, position, and ability to directly "move the needle" through personal contribution, i.e. the ability to directly influence the outcome of the metric must be in the realm of those being measured. (Wolbert, 2007)

3.9 Summary of Literature Review

From available literature, the creation and implementation of a visual management system should really be to meet a broader need of the enterprise, and that an evaluation of the enterprise's value stream should be performed to determine what tasks or functions need to be coordinated. In addition, value-adding jobs should be performed by those with the least resource cost, either in time, money, or human resources.

When "macro pulls" such as market standards, customer constraints, or strategy indicate that an ERP system is needed, management must recognize it will have implications both positive and negative for the enterprise. Architecture of the product will dictate which functionality is necessary in an ERP system, and vice versa. Likewise, other macro pulls may require an MES, and care should be taken that its features and functionality contribute to a lean enterprise.

Furthermore, the Enterprise value stream could reveal there are other tasks/functions which might be fulfilled by the use of a visual management system, but it should interface with the other systems efficiently. These other tasks or functions normally take the form of timely production control, defect or abnormality identification, and metrics reporting. In its simplest form, a visual management system uses visual cues and tools to provide all operators with clear and concise communication, which is easily understood across languages and cultural differences. As visual management tools evolve, manufacturers should continuously evaluate and use them as part of any lean strategy and drive for continuous improvement.

Even though the idea for a visual management system might originate from middle management or be disseminated as part of the enterprise's strategy, the end-user will be required to pull the change if the system is to be sustainable. This is the big challenge for management, to turn a top-down initiative into a grassroots campaign. Visual management will only work if a critical mass of end-users buy-in and support the underlying assumptions that 1)there are problems with the status quo and improvements to be made (micro pulls), 2) the visual management system will solve these problems, and 3)the benefits to the end-user outweigh the costs to the end-user. Systemic linkages and interfaces constitute the enterprise's architecture and are required to enable the system. This will include IT to IT, IT to human, and human to human interfaces.

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4 Case Studies of Lean in an ERP/MES driven environment

Consistent with the approach set forth in the literature review regarding Enterprise

Transformation, the current state of production was evaluated and compared with the enterprise's

value proposition. This approach produced a list of functions and abilities to be built in to the visual

management system. From this list, alternate enterprise architectures were implemented in series

to find the one which allowed the enterprise to maximize total value.

4.1 Problem Statement

As mentioned above in 2.4, ABSCompany was implementing a Lean Culture Change Initiative.

The site had already progressed through the first two planning and infrastructure phases, and the

next phase gate had several requirements surrounding visual management systems and processes to

support smooth production flow. The minimum requirements, shown in Table 5, were chosen in

order to reduce lead time, inventory, and cycle time without negatively impacting cost and quality.

Site leadership hoped to make the site a world class benchmark manufacturing site and initiated a

research project to exceed the minimum phase gate requirements by creating a system which created

more enterprise value.

Table 5: Visual Management system minimum requirements, as prescribed by the ABSCompany Lean Culture Change Initiative.

5S	Sort, Simplify, System Clean, Standardize, Sustain
Metrics	Site/Business metrics
	Cell metrics (safety, quality, productivity, delivery, cost)
Andon	Escalation process implemented in critical locations where there should be a rapid reaction from operations
Problem Visualization and Tracking	Problems, countermeasures, ownership, & timeline
Material Controls	Identifies amount of inventory, what is worked next, and abnormalities (missing materials)
	Utilizes pull system, kanban system, supermarket, and replenishment actions
Production Status Controls	Bottleneck Identification
	Visual ahead/behind conditions
	Process maps for people, machines, and materials

A production cell was chosen for a pilot program. When successful, this production cell would be used to showcase the new system and transfer knowledge between other on-site production cells.

4.2 Enterprise Initial State

According to prevailing Enterprise Architecting theory, an analysis of ABSCompany was performed using the eight views of strategy, policy, process, product, service, knowledge, information, and organization (Nightingle, 2008). While a much more lengthy analysis could be written, only those aspects which touch on the visual management system are included here.

Strategy- The site, as a sub business unit of ABSCompany, had to both contribute to the revenues and compete with other sub business units on cost, quality, and capacity utilization . This intra-business unit competition was aimed at winning business, both new business and business transferred from underperforming sites. Such transfers were rare due to expenses of moving capital

and resources, but an award of new business could lock in a revenue stream for the life of the product, potentially 20 or more years. For this reason, each site was interested in minimizing operational footprint while maximizing output, as new business was awarded to efficient sites with open floor space. In the preceding year, the site was named the most improved site, and site leadership was outspoken about maintaining momentum.

While long-term ramifications of any strategic decision were considered, short-term effects weighed heavily. This is not to say that ABSCompany operated in a shortsighted manner, but rather improvement projects generally required a payback period of a year or less and had to support long-term strategic goals to be under consideration for investment.

Quick and successful phase gate completion of the Lean Culture Change Initiative was also of strategic importance. For this purpose, the Lean Culture Change Initiative called for a site-based change agent to select a leadership council out of well-performing, change-oriented individuals in engineering, sourcing, planning and asset management, manufacturing, all IPT's, etc. which met with site staff weekly to discuss progress.

Organization- While organizational structure was already discussed in 2.3, a few items remain which are worth addressing. The IPT structure was relatively new, changed from a more functionally-oriented structure during an earlier Lean Culture Change Initiative phase. Some disagreement about the change remained, because the products made in each of the IPTs were very similar. In some cases, the exact same subassembly was built in multiple places on the production floor.

Next, the site was moving toward self-directed teams. Consistent with the lean principle of worker empowerment, decision making was being pushed down the hierarchy. Over the years,

headcount had come down, and each employee carried more responsibility. Operators were more empowered and acting more collaboratively.

Policy/External Factors- The nature of the business and its customers required close government regulation and quality assurance. Even a single quality escape would drastically damage the site's quality rating, given the relatively low number of products shipped per year (ca. 4000 units). As a result, the Quality function was one of the largest on site, overseeing incoming and outgoing inspections, revision control of standard work, employee training, and engineering change re-certifications.

Many customers had source inspectors on site, and ABSCompany gained significant trust by offering transparency to all customers. In the previous years, compliance to customer-required policies and processes and a good quality track record had led many customers to relax the need for on-site source inspection, a vote of confidence the site leadership did not take lightly.

Process- As mentioned above in Policy/External Factors, compliance to policies and processes was paramount to winning and maintaining good customer relations. Internally, the push for standard work, even for leadership and engineering tasks, had strengthened the site's process-oriented culture. Process improvement was a central focus of the site's continuous improvement program.

However, there seemed to be a constant tug-of-war between standardization and autonomy. For example, while the Lean Culture Change Initiative required standard metrics boards and morning meeting routines, business needs of each cell could vary slightly, and IPT's were given some latitude to adjust processes as appropriate. These small, isolated improvements were then passed through the business as new best practices, which often led to the site's official process being updated

Products- Product architecture was very modular. For the pilot production cell, the product family allowed 35+ customer required configurations from approximately 10 interchangeable parts. This allowed a nearly identical Bill of Materials structure which varied by only a few part numbers. Parts and subassemblies were very expensive and typically had long lead times or inflexible delivery schedules. Part and supplier obsolescence were major factors driving an almost continuous cycle of engineering change orders and supply chain uncertainty.

Services- While this particular site of ABSCompany did have an aftermarket support division, the site had very little to do with services, so no meaningful analysis could be drawn from its services.

Knowledge- As with many competitors in the industry, much of the knowledge base was in the heads of the employee base, and ABSCompany was facing a significant brain-drain issue with the pending retirements of the baby boomers. Site leadership was aware and constantly looking for ways to capture knowledge and make it more available to others. The site had a significant training budget which was to be shared between operator certifications and the extensive training associated with the Lean Culture Change Initiative.

Information- Due to the many factors which will be addressed in more detail in section 4.2.1 below, the site had implemented an ERP and MES system three years previous, and personnel were generally familiar with the systems. Beyond the ERP/MES, there were many software in place throughout the facility, owed to the long list of legacy products still being manufactured. Generally, hardware and software compatibility was a significant issue for the site.

4.2.1 Existing ERP and MES Systems

When viewed from an enterprise value stream perspective, ABSCompany was certainly large enough that management and coordination of its assets was necessary. ABSCompany had grown in recent years through a number of mergers and acquisitions, and corporate had decided years ago to consolidate its long list of redundant and conflicting software to an ERP backbone with a short list of approved bolt-on software applications. The ERP would provide a common language and database for all transactions given in 3.5, namely finance, sales and marketing, operations and logistics, human resources, and materials management. By doing so, sourcing could consolidate demand and combine commodity purchasing power over the entire enterprise, preventing individual sites form bidding up commodity prices against each other. Furthermore, an ERP would act to align and standardize processes and reporting over all business units and functions.

Even though the ERP did bring many competitive abilities to ABSCompany, it was recognized that there would be other implications, both positive and negative, for the organization. In ABSCompany's case, the ERP contained the Bill of Materials, which became the go-to place for engineering change control.

One negative aspect of the ERP was that each successive level of the Bill of Materials had its own non-zero lead time requirements. To illustrate this, examine Table 6 below which shows the operations and processing times for each of the stations in the pilot production cell.

Table 6: ERP and actual processing times by build station.

Operation	Actual takt time	ERP effective processing time
Station 1	90 minutes	1 day
(Queue time)	0-?	
Station 2 (3 shorter operations)	60 minutes	1 day
(Queue time)	0-?	
Intermediate Test	12 hours	1 day
(Queue time)	0-?	
Station 3 (2 shorter operations)	40 minutes	1 day
Total=	15 hours, 10 minutes + Queue time	4 days

For each level of the four levels of the Bill of Materials for a given part, the ERP system had a minimum lead time of one day. This meant that the ERP would schedule one day processing time for each, for a total of four days, even though the actual, total processing time could be as short as 15 hours. This meant that the ERP system brought in materials sooner than they could actually be used, building up excess inventory. Another drawback was the ERP minimum processing time prevented accurate capacity planning because parts could travel quickly and complete several operations, but ERP could not plan that way due to the minimum 1-day lead time per operation. Planners had to manipulate lead times to get parts to release on time.

Second was the time lag associated with the ERP, when it was used in conjunction with the MES. This time lag of information in the ERP had several effects on operations, such as critical staff meetings and weekly corporate production and revenue reports being timed around when ERP was considered most up to date (i.e. Monday morning, after weekend overtime was kept to a minimum). Furthermore, much of daily production planning had to be done late afternoon or early morning before production and ERP delay caused discrepancies.

Even site metrics were influenced by what the ERP was able to produce. The ERP reports module could not generate a report for everything due contractually in one week (for on time delivery metrics). To circumvent this inability, the manager had to export a report of open shop orders, sort, filter, and otherwise manipulate the date to a list of sales orders due in a given week. The process often depended on Master Schedulers to watch for things which might have been missed. In the pilot production cell, for example, the dollar value of WIP inventory could not be reported directly. Instead the number of subassemblies were tracked and then multiplied by average price.

The MES also filled enterprise value needs which the ERP could not do, such as being able to enable the attribution of operator production time and activities to corresponding customer accounts for financial purposes. While usually requiring an additional software application, the MES essentially allowed an operator's time to be "charged" to a certain product. Likewise, customers required intermediate quality checks which were embedded in the standard work instructions, without which the part could not progress to a subsequent operation. A record of these quality checks, with corresponding time and responsible party, was archived as part of the part serial numbers, pedigree, and build history.

Another value the MES provided was to deliver standard work instructions. In contrast to paper standard work instructions, computer network-issued standard work instructions were automatically revision controlled, always issuing the latest engineering-certified instructions and eliminating the danger of having old instructions floating around the shop. An operator need only scan in the paper traveler accompanying the part, and the next build step's work instructions would be summoned from the Document Control Center.

Next, the MES could better account for progressing products through sequential build operations. Since the MES issued the standard work instructions and kept track of intermediate quality checks, it kept track of products better than the ERP, which would download this same data from the MES with a considerable time delay of up to an hour. Because of this, an operation which consumed two subassembly parts could not be immediately reflected in the ERP, rendering an accurate inventory "snapshot" impossible during a given workday. This complicated the tactical planning process, because parts appeared in the ERP to be available for assembly for an hour after they had actually progressed to the next step. For everything where accuracy was required within a given work day, the MES was the usual information source. For longer range supply chain planning, the ERP was the source. This meant that early in the morning was the most accurate time for the ERP system, and planners and managers used this time to get the best reports.

4.2.2 Production Initial State

4.2.2.1 Information flow Schematic

Planning and production execution was a process involving IT systems and human processes. A schematic of information flows is shown in Figure 1, the nodes and links of which are explained below.
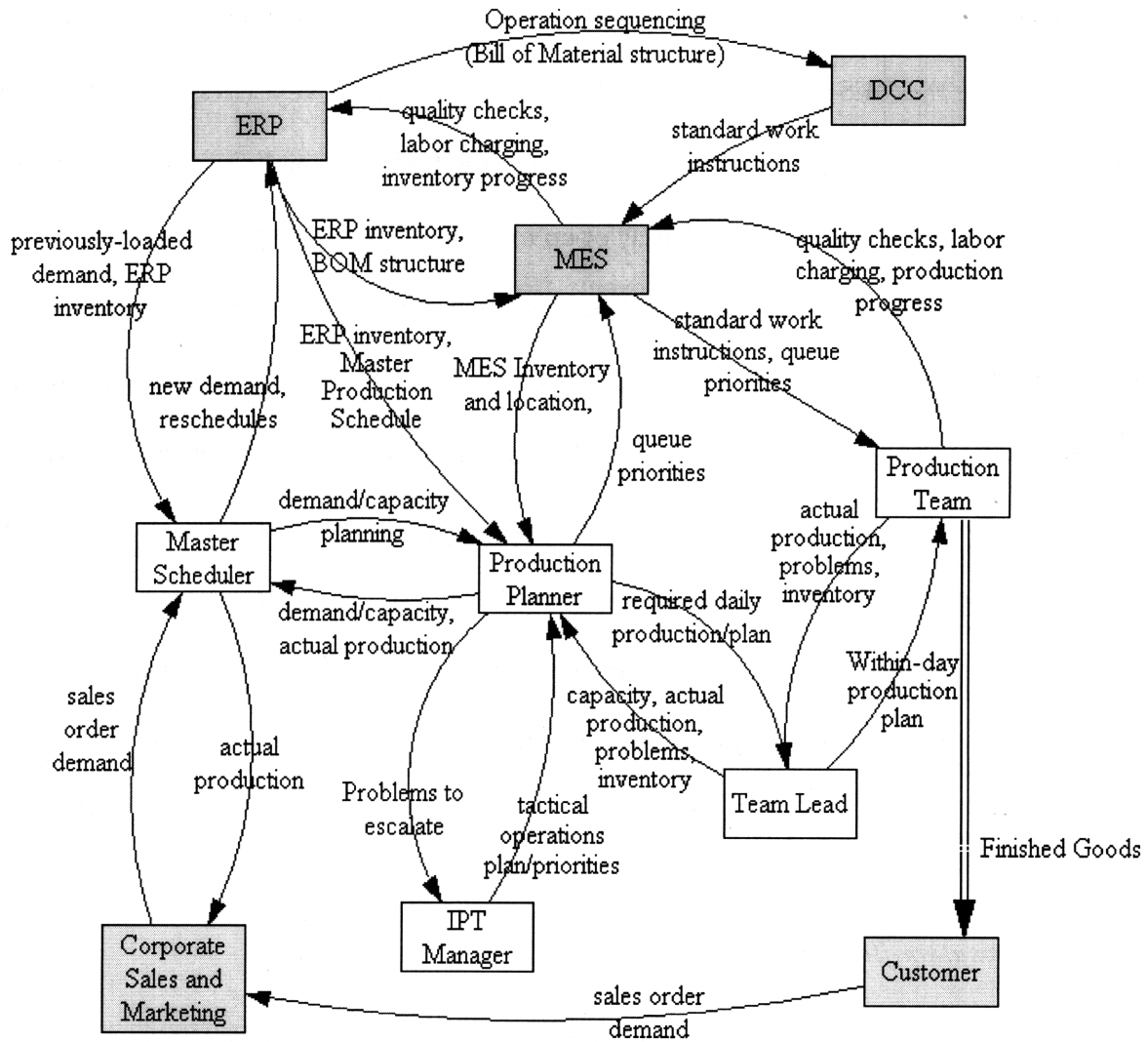
Figure 1: Initial state (Version 0) of information flows associated with production.

Corporate Sales and Marketing: Sales and Marketing worked with customers to obtain sales orders for ABSCompany's products. Sales orders consisted of how many of which product are due on which day, and no sales order was accepted inside the standard six month lead time. When a sales order was obtained, its information was turned over to the IPT's Master Scheduler.

Master Scheduler: Knowing when the sales order is due, the Master Scheduler examined the existing production schedule and entered the sales order's finished product number, as a unit of "demand", into the site's ERP system. Choice of production due date was no arbitrary date, as the Master Scheduler had to consider several factors including production level loading, production capacity, inventory availability (especially when components were shared across multiple IPT's), and other site-related issues affecting the ability to deliver the product on time. The Master Scheduler worked closely with the Production Planner on capacity/demand loading scenarios. On the tail end of production, the Master Scheduler also checked the ERP shipping information, reported actual booked revenue with corporate each week, and had to answer for any missed projections.

ERP: With finished product number "demand" loaded, the ERP calculated when all components should be ordered or produced, based on the most current Bill of Materials and each component's lead time. The sum of all finished product-level and sub-assembly level demand combined to form the site's Master Production Schedule (MPS), which then became the standard measure against which to measure the site's revenue and cost schedule.

MES: The MES system operated in conjunction with the ERP system. It provided real-time production support, including delivering standard work instructions and conveying labor charging and quality check information to the ERP, in order to be stored as part of the product's genealogy.

DCC: Document Control Center, the group within Quality responsible that the most current engineering-approved standard work instruction is available when the production floor "calls" the MES for a particular set of work instructions.

IPT Manager: The person responsible for coordinating all IPT operations, including scheduling, planning, and production execution, including deciding action plan under uncertain

supply chain conditions. The IPT Manager is also responsible for coordinating the shared use of resources with other IPT Managers, including shared parts, testing stations, and labor.

Production Planner: The Production Planner was primarily responsible for making sure the Master Production Schedule (MPS) is carried out. This meant following up on external sourcing and internal production areas which fed subassemblies to the pilot production cell. This involved diving deep into the many levels of the Bill of Materials to make sure everything was "clear-to-build". In theory the Planner would not need to plan anything if the ERP were designed to release shop orders. Instead, the Planner had to take the high-level production plan, break it down into a series of concerted subassembly operations, and release shop orders. Normally, the Planner turned over this more finely-tuned sequence of building to the Team Lead, but the pilot production cell did not yet have one, so the Planner assumed the responsibilities of the Team Lead.

Team Lead: The Team Lead took the numbers of what had to be produced in the coming couple days and filled in the details of who produced what, when, and at which workstation. It was this simple concrete plan which was communicated through the daily production board as described in section 4.2.3. The Team Lead was responsible for communicating capacity or escalating any problems, such as inventory discrepancies which hindered production, to the Production Planner.

Production Team: The production team executed the Team Lead's plan. This involved interfacing with the MES system for standard work instructions and intermediate quality checks.

One caveat to the planning and execution process which is worth noting, however, was a hierarchy of schedules, one contractual, by sales order and line item, and the other the site's Master Production Schedule. Meeting contractual dates contributed to the most important deliver metric, On Time To Request (OTTR). Since the MPS was site specific and more or less site-controlled, a number of metrics spring up to measure its success, such as "% MPS on time to completion". It

was in the Master Scheduler's interest to plan the actual production to take place safely before the items were contractually due, subject to contractual shipping windows and other customer-specific needs.

Perhaps more important was to witness several specific operational issues which should improve through a good visual management system, which included low Master Production Schedule compliance, frequent shortages and line-stoppages, poor operational visibility, and sub-goal productivity, which will be dealt with in the subsequent sections.

4.2.2.2 Master Production Schedule compliance

While OTTR was steady at about 99%, MPS compliance averaged about 35%. The discrepancy between the two indicated several characteristics of the site. First, the Master Schedulers were quite knowledgeable about how much buffer time should be built in between contract dates and MPS dates. Second, management was very adept at solving operational problems to get product out the door. Lastly, because the production team could usually depend on a time buffer, it was assumed a slight slip would not result in catastrophe.

4.2.2.3 Shortages and Stoppages

In spite of the a month minimum planning horizon and a three month frozen-window, management spent considerable time resolving shortages and stoppages in operations. A shortage was defined as any component which would run out and starve production in the next six weeks unless all scheduled replenishment shipments are received. A stoppage was the event when a part or component is missing from its point of use and caused a line-down situation, according to that day's production plan. Sometimes the stoppage designation seemed somewhat a misnomer, since most lines switched gears and either worked on a future day's production plan, at the subassembly or

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product level. The sources of these shortages and stoppages were all unique, and it often took a deep dive to get to the bottom of each issue. Most supply chain failures could be attributed to the long-life cycle products, changing supplier base, engineering change orders, and/or accompanying rushed procurement cycles.

4.2.2.4 Operational Visibility

As mentioned previously, supply chain operations were coordinated through the ERP, and the MES system passed through labor charging data, production standard work, and intermediate quality checks. In spite of these IT systems, there was a disconnect between the reality of work in process (WIP) inventory in various places throughout the factory and the inventory represented in the systems. This was largely due to physical location, time lag, and an ERP term called soft-pegging.

As a product progressed from raw materials to finished product, it moved from operation to operation through the factory. At each operation some value was added, including having components and sub assemblies installed, tests performed, or quality inspections performed. In parallel, a virtual product, designated by part and serial number stored in the ERP system, started at one level of the Bill of Materials and progressed to higher levels as components were installed. Work in process, depending on actual build step, was stored at multiple virtual, database storage locations, but, except for the last operation performed and the next operation to be performed, there was no connection to actual factory location.

This separate path process had several repercussions. It was difficult to look at a piece of work on a workbench in assembly, test, or shipping and determine when it was due and what end product, in terms of sales order and line item, it belonged to. Another was that products which failed intermediate tests entered rework cycles of varied duration. While it was true that the product had a

paper traveler which contained information linkable to MPS, the paper only stated what day that particular operation should start and finish, usually the same day. Any subassembly could be installed in any end product which required that subassembly.

This concept, that a subassembly can count as inventory and be counted available to match up with any end product, but not required to end up in that end product, is called soft-pegging. On one hand, it allowed a very useful degree of flexibility, because it enabled truly interchangeable parts, that a product was not held up because a ready-to-install subassembly was already "betrothed" to another end product, which had stalled for some reason.

On the other hand, it was difficult to distinguish whether the 3 subassemblies on the workbench were "destined" to be the ones necessary to fill next Friday's deadline or whether they would become part of another end product in the pipeline. So, when deadlines were tight, management and labor alike had to spend time figuring out what product, at various stages of production, belonged to which sales order, and whether it would finish in time. Thus, a connection between physical product on a workbench and the sales order for which it was being built was lacking.

The database time lag between the ERP and the MES was already discussed previously, but it likewise contributed to the confusion. Operations performed in the MES could not be reflected in the ERP for up to an hour, so there was considerable distrust in the numbers reflected in either system. The best time to check was in the morning, when both systems had time to catch up and reconcile, but as the day progressed, discrepancies were common.

Due to the multiple-level Bill of Material and long shop order release process, it was not uncommon to release and print shop orders for each step days in advance of actual need. All shop orders were grouped together in a file cabinet, and build personnel executed according to the day's

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production plan, as directed by the Production Planner. Dependence between the different levels of the BOM was not apparent. While it was true that every operator knew a subassembly W gets built into subassembly X, it was not apparent, for example, "If I don't get his done by lunchtime, it won't be ready for the next step, …which will prevent the required Friday shipment", unless the Production Planner communicated this urgent dependency verbally to both operators.

4.2.2.5 Productivity

During a time study performed a few months earlier, the operators had established standard processing times for each operation. Actual production times, however, could be significantly longer. Often, this could be justifiably attributed to operator learning curve, material availability, or the performance of quality checks for other operators. Occasionally, productivity would drop significantly, and management had to inquire, follow up, and encourage standard processing times.

Related to productivity, there was no way to see how lost productivity was causing the production cell to fall behind. When productivity was low, the day's number of produced units was less than planned, but there was no connection between the next day's plan and the lost productivity. No one knew, except the Planner, whether the next day's plan included recovery for the previous day's slip. The Planner just posted a new plan for each day. The production team had no visual cues as to how ahead or behind it was, and where appropriate, the recovery effort required to get back on track.

4.2.3 Visual Management Initial State

Some aspects of visual management had been implemented as site standards during the first phases of the Lean Culture Change Initiative. The first of these was a standard metrics board, a simplified version of which shown in Figure 2, which tracks daily trends in safety, quality, delivery,

inventory, and cost. A second board, called the Weekly Playbook (Figure 3), kept track of the how many end products of different types were completed each day. The last board, called the Daily Playbook (Figure 4), was a table with rows of daytimes in 90 minute increments and columns of job stations. It was on this board each day that the Production Planner wrote in white-board marker the operator names and subassemblies to be built per time block.

Safety- Any Near Misses? Any Recordable Incidents? Any safety related issues?				M	T	W	TH	F	S	S	TOTAL	What went well yesterday?						
Safety Cross		Required/ Plan																
		Actual/ Cumulative Difference (Actual / Plan)										Communications						
		# of Associates/ # of Total Hours worked																
		Productivity (Actuals/ Hours Worked)																

Notes			Action RAIL					WIP	MPS	LTC	Plan	Actual	Delta	MISC
		SQDIC/ Tier	Issue	Person Responsible	Due Date	Status	SMT							
							CCA L...							
							W...							
							SPOP							
							IC-T/SRU							
							HIC							
							B.../ C...							
							FIC							
Date	1st	2nd					W... 1							
Station 3							W... 2							
Station 2							W... 3							
Station 1							W... 4							
Test load/unload							W... 5							

Quality Metric	Delivery Metric	Inventory Metric	Cost Metric
Daily Escapes & Rejections	Actual vs. Required	Open Orders	Daily OT

Figure 2: ABSCompany standard site metrics board

Week	Weekly Playbook												
	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
	Plan	Actual	Plan	Actual	Plan	Actual	Plan	Actual	Plan	Actual	Plan	Actual
Product 1												
Product 2												
Product 3												
Product 4												
Product 5												
Product 6												
Product 7												
Product 8												
Total												
Delta												
Issues												

Figure 3: Original (Version 0) Weekly Playbook, used to keep track of execution against planning.

	Station 1 1 Set (90 min)	Station 1 1 set (90 min)	Station 2, op #1 (30 min)	Station 2, op #2 (20 min)	Station 3, op #1 (20 min)	Station 3, op #2 (20 min)	Test Load/Unload As Required (10 min/10 min)
4:00-6:00							
6:00-7:30							
8:00-9:30							
9:30-11:00							
11:00-1:30							
1:30-3:00							
3:00-4:30							
Second Shift							

Ground Rules
Complete what you started
Load/Unload high priority
Date

Team Playbook

People

Figure 4: Original (Version 0) Team Playbook, used by the Planner to communicate task assignments.

One operator was selected weekly to be responsible for leading the early morning team meeting, and accompanying this responsibility was to do a quick inventory count of all subassemblies. In addition, this individual had to calculate productivity by inquiring of other operators how much each had worked the day before and what products had left the area.

The actual meeting's agenda typically progressed as follows:

- Discussion of key metrics (SQDIC)

- Yesterday's issues (what went well, shortages, productivity hindrances, etc.)

- Current day's issues (problems encountered already or foreseen with plan, etc.)

- Review of everyone's assignments on the Daily Playbook.

Over the course of the day, operators communicated completion of an assigned job by writing "done" next to that job on the Daily Playbook. This was the only way to determine if the production cell was keeping schedule. At day's end, the team assembled again to review the day's activities, and it was after this time that operators clocked out, and the Planner wrote the next day's plan and updated the Weekly Playbook.

In the next sections, different enterprise architectures are devised to improve upon the current state in ways which address enterprise needs. Normally, a single enterprise architecture would be designed and implemented. For this project, however, a more iterative approach resulted as different stakeholder weights and values evolved in response to enterprise architecture experiments.

4.3   Enterprise Architecture #1

Enterprise Architecting theory teaches that a logical step after understanding the current state is to decide on a list of immediate stakeholders who will use the visual management system. Those identified were the production team, Production Planner, IPT Manager, and Site Director. In order to be aligned to the macro pulls and corporate strategy, site leadership was viewed to be the most important. The Site Director, who was a firm believer in simple, low-tech pull or kanban systems, was heard many times to say, "If it isn't on pull, it's not lean." Change Management theory also required that end-users be incorporated into the design process, if not fully responsible.

Usually, simple systems or processes are also cheap, and the site was already under pressure to reduce costs as the reality of the 2008 financial crisis settled in. While a fully-integrated IT solution

such as Raytheon's VBS system certainly had lifetime maintenance cost benefits, justification for internal software programming and a network of flat-screen monitors would have been a tough sell.

The existing ERP and MES systems were taken as given, in light of the operational values they afforded, so the value stream was examined to see what tasks and functions could be provided by a visual management system. One value it had to supply was the fulfillment of the visual management requirements of the Lean Culture Change Initiative, including the following three items. First, it should lend accountability and ownership to operators and immediate support staff. Second, key process indicators such as safety, quality, delivery, inventory, and cost (SQDIC) should be kept visual. Third, the visual management system should facilitate quick ahead or behind assessment for management pass-through inspection. This feature was referred to as "day by the hour", in that an operator's or station's assignments were to be clearly communicated in timed periods corresponding to standard processing times for each operation.

One value seen through the Organization View of the Enterprise Architecting framework was the need to shift some of the burden and risk from the Production Planner. Without a Team Lead, the Production Planner had to assume the extra tasks of coordinating the who, what, when, and where with all associated following up and problem solving, even though the Planner was not collocated with the pilot production team. The visual management system should therefore take a more active role in regulating production efforts, pushing some of the decision making to the cell, which was consistent with the worker empowerment principle. This was another reason why an approach such as Raytheon's VBS was not attempted, because VBS had been primarily used for status reporting, and its architecture did not appear to have planning capability.

In order to contribute to operational visibility, the visual management system needed to make inventory discrepancies apparent, especially where something should have arrived but has not. This was not only important for sourced parts, but maintaining visibility to parts which failed intermediate testing cycles and entered rework cycles was considered paramount. After all, parts which "stalled" in intermediate test could not be depended upon as part of that day's plan due to the uncertain return time. This process of verifying parts and assemblies were available for production was termed the clear-to-build process.

The other aspect of operational visibility which the visual management system was hoped to solve was the connection of physical part to its originating sales order. It was decided, however, that a stronger connection to the Master Production Schedule would be sufficient for several reasons. First, management did not feel that operators should be exposed to customer information directly. Second, management did not want production personnel to be second guessing or reprioritizing items in the build plan based on sales order information. If such reprioritization had to happen, it should happen between the Master Scheduler and the Production Planner. Third, sales order information was not readily available except in the ERP, yet most of the production floor was only trained on the MES, and MPS was common shop terminology. Lastly, management believed operators need only to be concerned with meeting the build plan and producing quality product.

To summarize, the architected design would need to produce the following enterprise values:

1. Incorporate pull-type mechanism.

2. Help regulate production, i.e. communicate the who, what, where, and when, and provide direction even when the Planner is unavailable.

3. Highlight abnormal conditions, especially consistent with clear-to-build, when parts are missing for production.

4. Provide visibility into intermediate test.

5. Provide end product visibility and connection to plan.

6. Encourage employee engagement, accountability, and ownership through system contribution.

7. Successfully meet Lean Culture Change Initiative minimum standards, such as ahead/behind and key metrics

4.3.1 Design Pilot, Implement, and Check Effectiveness

4.3.1.1 Design and Implement Pilot

Many of the Lean Culture Change Initiative minimum standards were already being met. 5S had already been implemented, and site metrics were already in order. The andon, or problem escalation, process was posted and operational. Problems visualization and tracking was accomplished on the standard metrics board. Besides improving the productivity cell metric, the visual management system would focus on the materials management and production status controls.

Regarding the pull system, technically the ERP was already a pull system since it only coordinated efforts for realized demand. What was meant, though, was to pull product through on a first-in-first-out (FIFO) basis as soon as materials were in position, as opposed to marching to the ERP 4-day, lock-step march. Given the high subassembly cost, high mix, and low volume of the product, it was not cost effective to maintain inventory supplies of all subassemblies. Instead, a

type-B kanban, sometimes called the recipe kanban, system was designed. A type-A kanban is one which is delivered to the next upstream station when demand is realized, whereas a type-B kanban is one which is delivered to the first upstream station, and the "recipe" kanban then dictates what operation is performed and what parts installed at each subsequent station.

It should be noted that at the time the system was to be designed, the Production Planner and production team were very busy dealing with complications due to an engineering design change and were not available for "unproductive" system brainstorming and designing activities. While management knew their input was valuable and wanted them to contribute, getting a half day was a tough sell in light of strained training budget and need keep up with the production schedule. Available resources to design the system and provide guidance were the production cell's quality engineer, who was doubling as the manufacturing engineer, the IPT manager, the Site Director, and the site's lean experts. The visual management system, therefore, was designed in parallel to ongoing production activities, and a short training session was used to explain how the system worked.

In order to better understand the kanban system's functionality, the flow of product within the cell should be discussed. There were three basic build stations with one intermediate test step between station 2 and station 3. At the second and third workstations, assembly activities were further subdivided into two nearly-equal operations. Assemblies completing the second operation at station 2 were loaded into a test fixture and delivered to the test group. Since the test machines processed in batches of 4, deliveries to the test group were made in batches of four according to a test appointment arranged by the Production Planner. Test time was typically 12 hours for each batch. There were usually two operators assigned to station 1, and each operator built an assembly which required 90 minutes. See Table 7 for processing times for each operation.

Table 7: Standard processing times by station and operation.

Operation	Takt time
Station 1	90 min.
Station 2, operation #1	30 min.
Station 2, operation #2	20 min.
Load/Unload	10 min.
Intermediate Test	12-24 hr.
Station 3, operation #1	20 min.
Station 3, operation #2	20 min.

Kanban queues mirrored this product flow, with four different columns representing the three build and one test operation, as shown in Figure 10. The pull signal came from an end product's due date in final test, which was readily available in the ERP's MPS. This date, which was specific to each individual end product, was recorded at the top of each kanban card, and kanban cards were placed in the start queue in MPS order. Cards, and accompanying parts, progressed on a FIFO basis from operation to operation, by taking from the top of each queue and, after completing the operation, placing at the bottom of the next queue. When an assembly failed test and entered the rework loop, this fact was communicated to the cell at the morning meeting by test personnel, and an orange clip was placed on the failed assembly's kanban card. The orange dot communicated the assembly was not to be expected at station 3 until rework was completed. A sample kanban card can be found in Figure 5 .

Product 1		MPS Due to Test							
Station 1 - assy 10	Station 2 - assy 20			Station 3, Operation 1 - assy 30			Station 3, Operation 2 -		
part a	assy 10	part e	part g	assy 20	part m	part r	assy 30	part w	part z

Figure 5: Type-B kanban card, product configuration traveler.

All the Planner needed to do under this visually managed production system was to load MPS-dated kanban cards in the Station 1 queue, assign each operator a station, and make a goal for the number of cards to advance to the next column. Operators pulled cards through the process and incremented up the "actual" count when a kanban card moves from one column to the next (see the Actual/Plan card at head of each column in Figure 10). When an operator found his queue empty, he or she took from the preceding queue and executed that operation, then reverted back to his own station's queue. In this regard, team members saw where bottlenecks were forming and shifted resources to alleviate those bottlenecks. Therefore, the system itself worked to solve the "who, what, where, and when" of production planning.
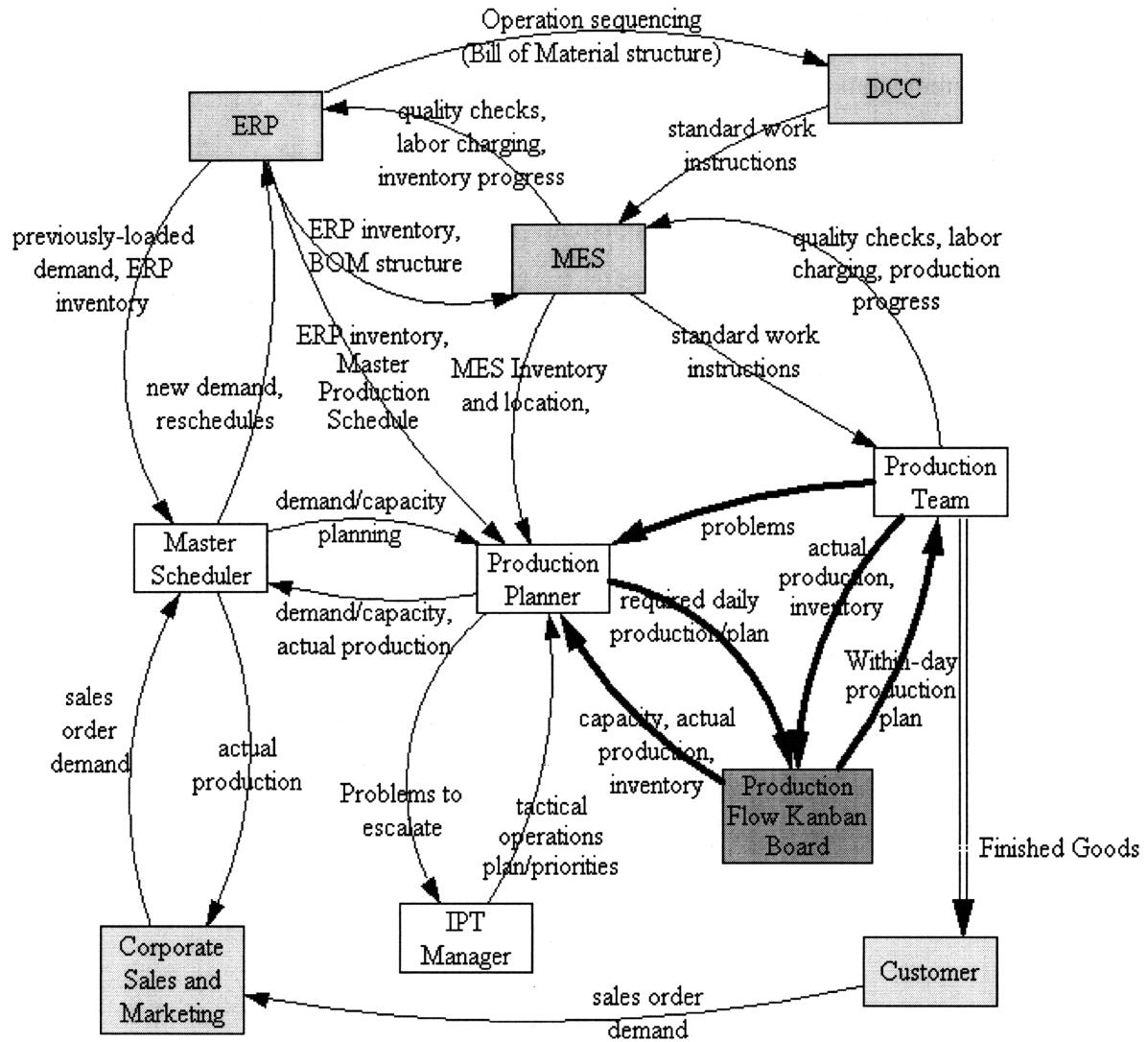
Figure 6: Enterprise Architecture #1 (Version 1) of information flows associated with production.

In order to provide the enterprise value of verifying the build plan was clear-to-build, a look-ahead function was built into the kanban card. Along the bottom edge of the kanban card was a color-coded row of all the different subassemblies built into each particular configuration. By counting up the different colors for each subassembly type in each kanban column and comparing with the inventory count made every morning, it could be determined, for example, that subassemblies were on hand for the next 15 units, which equates to about 1 ½ days of inventory for

that particular subassembly. Conversely, if actual count were zero, but the parts would be needed in two days, the system would catch it, and the escalation and problem solving process could be initiated before the line went down.

In order to improve productivity accountability, a revised Daily Playbook was designed, which is shown in Figure 7. Instead of operators writing "done" next to assigned tasks as in the original Daily Playbook, operators wrote in beginning and end times of tasks actually performed. Underperforming operators either had to record job times in excess of the standard processing time or leave open spaces between productive tasks. In either case, operators had to account for any issues which hindered timely production, and the reasons were discussed at the next meeting. The addition of the second column also allowed the record to remain for the next day's morning meeting instead of being erased to make room for the next day's plan.

Team Playbook

Legend:
St1.1 = Station 1.1 - 90min/set
St1.2 = Station 1.2 - 90min/set
St2.1 = Station 2.1 - 30min/block

St2.2 = Station 2.2 - 20min/block
TL/UL = Test Load/Unload - 10 min/10 min
St3.1 = Station 3.1 - 20 min/block
St3.2 = Station 3.2 - 20 min/block

Date:	Worker 1	Worker 2	Worker 3	Worker 4	Worker 5		Date:	Worker 1	Worker 2	Worker 3	Worker 4	Worker 5	
6am							6am						
	Tier 2 & break	Tier 2 & break	Tier 2 & break	Tier 2 & break	Tier 2 & break			Tier 2 & break	Tier 2 & break	Tier 2 & break	Tier 2 & break	Tier 2 & break	
8am							8am						
10am							10am						
12pm							12pm						
2pm							2pm						
4pm							4pm						
Issues							Issues						

Figure 7: Version 1, Team Playbook. This board helped track productivity by operator.

One of the last main attributes of the visual management system was the revised Weekly Playbook to be a Two-Week Playbook, as shown in Figure 9. By recording not only the plan and actual, but also the new required and cumulative past due, as detailed in Figure 8, the production team saw how it was falling behind by missing planned numbers. Furthermore, the extra week planning horizon made visual the need to meet productivity targets in order to recover lost production.

	Week # Date:			Week # Date:		
	Monday			Tuesday		
	Required MPS Cumul. Past due	Plan	Act.	Required MPS Cumul. Past due	Plan	Act.
Product 1	3 / 4	5	4	4 / 3	6	6

Figure 8: Detail of Two-week Playbook, showing accounting used to keep cumulative past due (backlog) visual.

Figure 9: Version 1, Two-Week Playbook. This chart helped track plan vs. actual and backlog at the unit level.
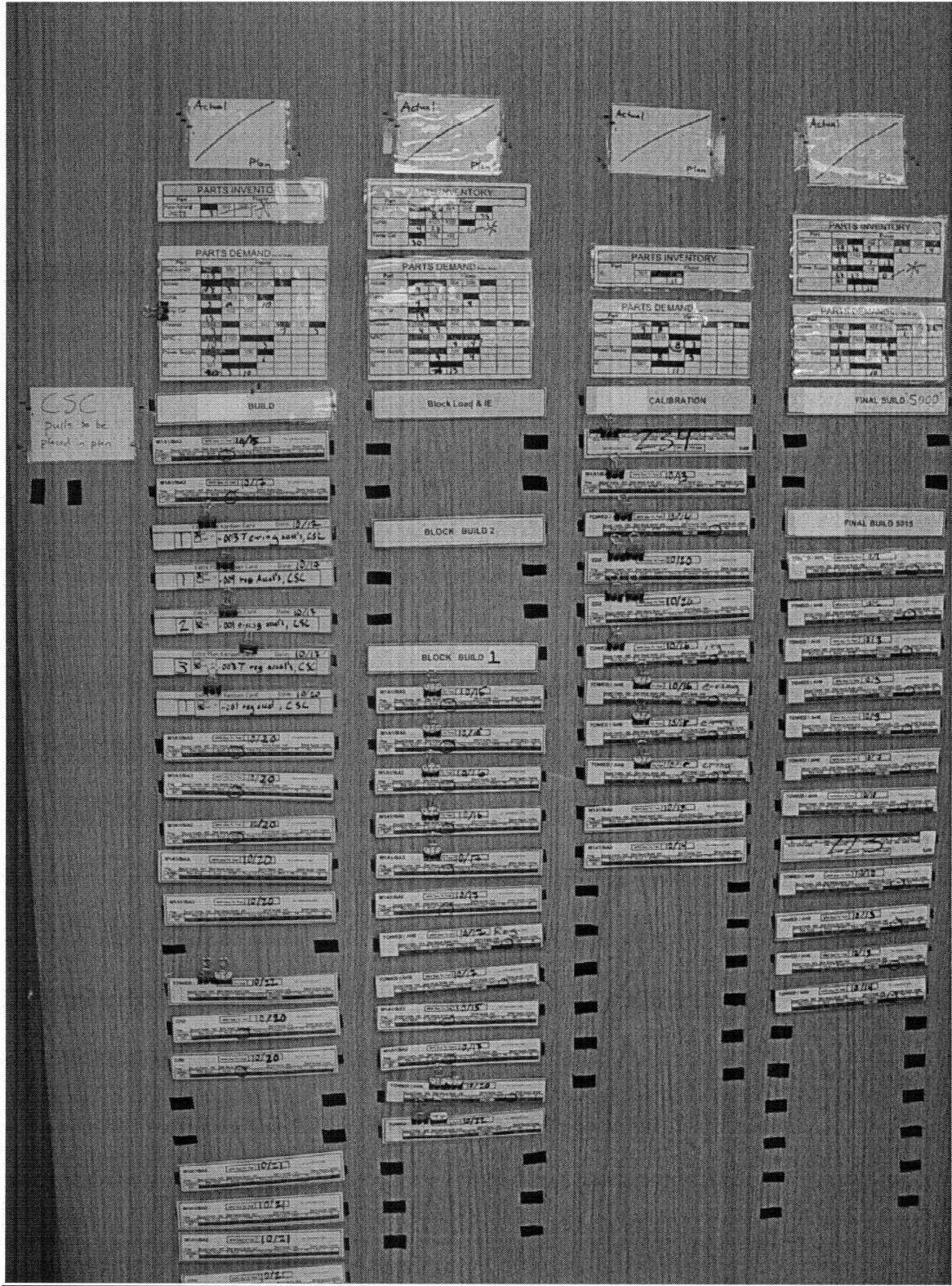
Figure 10: Version 1, Production Flow Kanban Board

4.3.1.2 Check Effectiveness

The first visual management system was able to accomplish much of what it set out to do. It achieved end-unit visibility and empowerd the production cell to make more autonomous decisions. It provided a very simple tie to MPS, both through the kanban cards and the cumulative past due figure in the Two-Week Playbook. Generally, products moved on a FIFO basis in a single-piece flow fashion. Inventory levels and bottlenecks at locations became apparent, including in the rework loop, which spawned other improvement projects. There was greater standard processing time visibility and accountability. The clear-to-build process, when followed, enabled a useful look-ahead at production need. Most importantly, the production team created a pull environment; everything was built with an end product in mind, instead of building subassemblies to stock inventory at different locations.

After five weeks, however, some conditions made it apparent that a few aspects of the new system were not compatible with the rest of the enterprise architecture. Operators viewed the processes, such as getting out of one's seat to transfer kanban cards and increment up actual vs. plan, as adding no value. Having to record standard processing time generated distrust and ill will. To many, the Production Flow Kanban Board, with all its colors, numbers, and letters, looked information-excessive and "dizzying". The clear-to-build process was tedious, and many managers questioned the need to have such information in the manufacturing cell. Most condemning of all is how quickly if fell out of alignment when the cards were not moved correctly.

To compound the problem, as far as the Planner was concerned, the planning job did not become easier. While the system should have been robust enough to simply load kanban cards in the station 1 queue and let the system run itself, the engineering design change was causing severe supply chain disruptions. For a time, it seemed that every card on the board was stopped for one

part or another. The new system was a burden to the Planner, because the supply chain disruptions made it necessary to shuffle the order of the kanban cards to make sure the correct units were worked on at each step. Thus, rescheduling was much more difficult for the Planner than simply revising a few assignments on a whiteboard.

Perhaps most importantly, however, the visual management system was not able to garner the critical mass to make it true, lasting change. The system was surely not designed or even influenced by the end-users, who had been too busy to include or consult. It was stated earlier that visual management, as a grassroots campaign, will only work if a critical mass of end-users buy-in and support the underlying assumptions that 1)there are improvements to be made, 2) the visual management system will solve these "micro challenges", and 3)the benefits to the end-user outweigh the costs to the end-user.

To the first point, the operators perceived no need for a new visual management system, so there was no burning platform. Few saw the utility of trying to exceed the minimum required by the Lean Culture Change Initiative and attempting a more complex system. The site had been recognized for its great improvements and made record quarter revenues twice in a row, all with the previous system. To the second point, most, if not all, of the team members were reasonably satisfied with the status quo, so there did not appear to be any problems to be solved. To point three, the end-users bore all the costs, in the form of extra tasks to perform, but the benefits of the system were supposed to be reaped by the Planner and by management, who could now better see the status of production.

Not only did the costs outweigh the benefits to the end-user, the new system exposed the production team to more risk, risk that a decision they were empowered to make was an incorrect

one. The sentiment was that they did not design the system or agree with some of the underlying lean principles like single-piece flow. The system could not really take the blame if the supply chain hiccupped, because the operators were empowered to overstep it to do the next best logical thing. Given this risk, most operators preferred having a simple, no risk, executable plan.

4.4 Enterprise Architecture #2

Revising and reprioritizing the list of stakeholders greatly shaped the second architecture, especially in light of the looming year end sprint. Of immediate enterprise value was recovering from the MPS slip caused by the engineering design change and accompanying supply chain disruption in order to meet revenue commitments. In this regard, the needs of the Planner were moved forward.

Also, management agreed the scope of the visual management system, at least for the time being, should be scaled back to better match the standard visual management boards throughout the factory. This meant not requiring the second system to provide the enterprise value of helping to regulate or coordinate production. The site was set to be reviewed for passing the third phase gate of the Lean Culture Change Initiative, and it was very important that standardization prevail and have all requirements met perfectly.

To summarize, the architected design would need to produce the following enterprise values:

1. Successfully meet Lean Culture Change Initiative minimum standards, such as ahead or behind and key metrics

2. Ease Planner's burden by use of simple processes.

3. Highlight abnormal conditions, especially consistent with clear-to-build, when parts are missing for production.

4. Provide visibility into intermediate test.

5. Provide end product visibility and connection to plan.

6. Encourage employee engagement, accountability, and ownership through system contribution.

4.4.1 Design Pilot, Implement, and Check Effectiveness

4.4.1.1 Design and Implement Pilot

As mentioned above, satisfying the Lean Culture Change Initiative requirement for phase gate completion was the most important, and ease of communicating a simple, executable build plan was second. The visual management system made use of a revised Daily Playbook, shown in Figure 12 with a very simple mechanism to communicate task completion. Upon close examination, the Playbook resembled the original Playbook, but instead of writing the assignments in whiteboard marker, the assignments were in the form of small cards affixed in each time slot with Velcro. An example of the cards is shown below in Figure 13. When the task was completed, the operator simply flipped over and replaced the card.
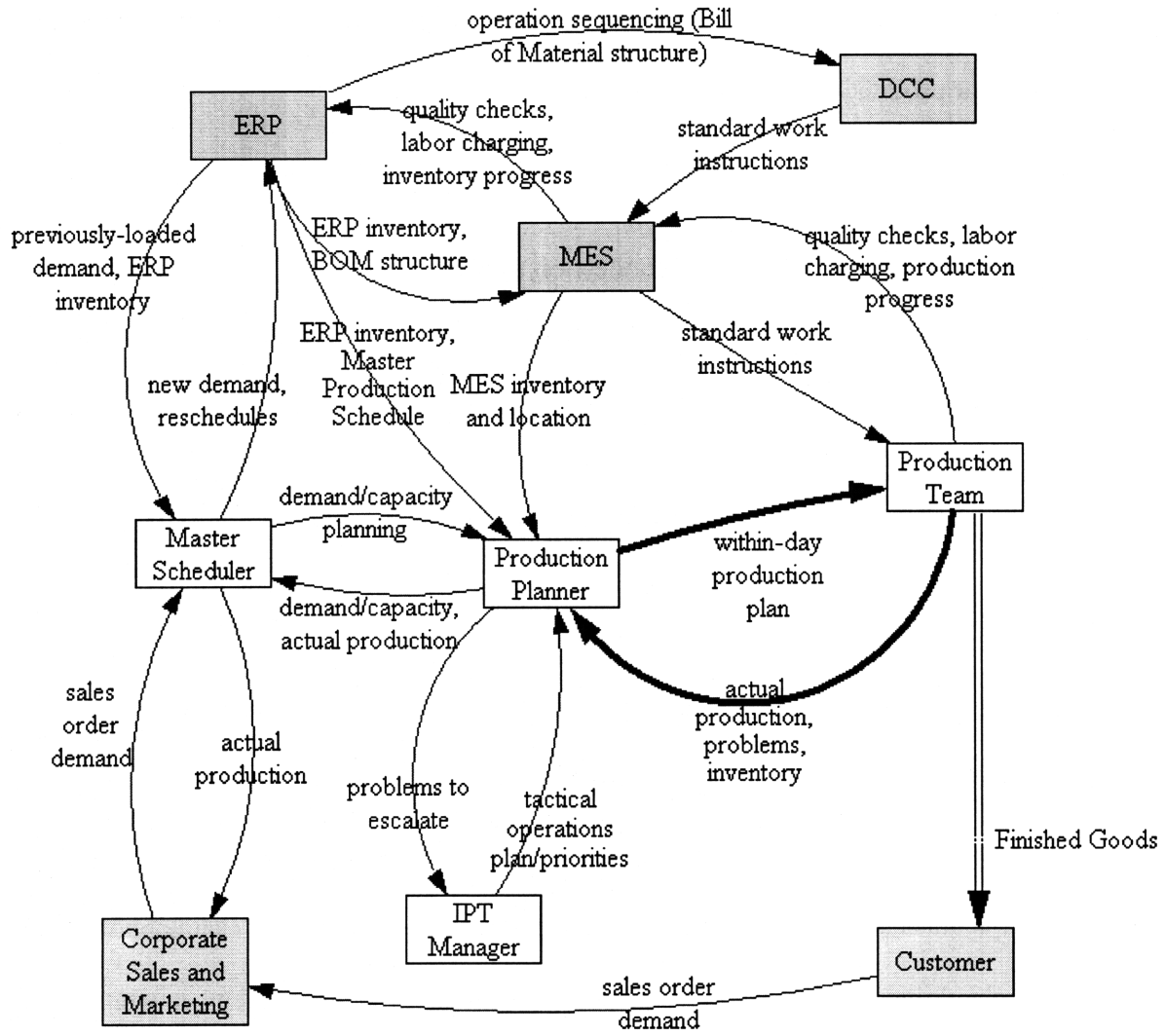
Figure 11: Enterprise Architecture #2 (Version 2) of information flows associated with production.

Date:	Station 2	Comment Regarding Delays		**Daily Playbook**			Date:	Station 3	Comment Regarding Delays
6am							**6am**		
7am				**Personnel Plan**			**7am**		
				Station 1, #1					
		Tier 2 Meeting		Station 1, #2					Tier 2 Meeting
		Break		Station 2, #1					Break
8am				Station 2, #2			**8am**		
				Load Unload					
				Station 3, #1					
				Station 3, #2					
9am							**9am**		
				Station 1 Build Plan					
		Break							Break
10am				assembly 1			**10am**		
				assembly 2					
				assembly 3					
				assembly 4					
11am							**11am**		
				Workcell Inventory	Date:				
12pm		Lunch		Assy. A	QTY	Assy. D	QTY	**12pm**	Lunch
				Type 1		Type 1			
				Type 2		Type 2			
2pm				Type 3		Type 3		**2pm**	
		Tier 1 Meeting (break > 10 hours)		Assy. B	QTY	Assy. E	QTY		Tier 1 Meeting (break > 10 hours)
				Type 1		Type 1			
3pm				Type 2		Type 2		**3pm**	
				Type 3		Type 3			
				Type 4		Type 4			
4pm				Assy. C	QTY	Assy. F	QTY	**4pm**	
				Type 1		Type 1			
				Type 2		Type 2			
				Type 3		Type 3			
				Type 4					

Figure 12: Version 2 Daily Playbook. This board was used to keep track of which operations were ahead of or behind schedule.
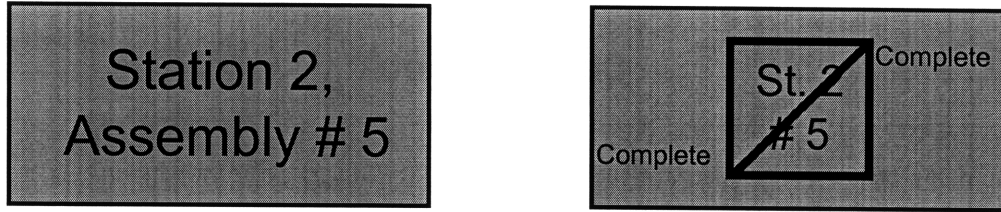
Figure 13: Version 2, front and back sides of the cards affixed to the Daily Playbook with Velcro. The card was flipped when a job was completed.

The Two-Week Playbook, with the Cumulative Past Due fields, remained the same. It should be noted that time is divided into 30 minutes buckets, and only two build steps are controlled here, namely block build and final build. Station 1 subassembly build was simplified to a daily rate of 2 different types, due to the reduction in subassembly count from a quickly processed engineering change order. Also, inventory was recorded in tabulated form in the middle of the table for all subassemblies and parts.

4.4.1.2 Check Effectiveness

The second visual management system excelled at delivering a simple, executable plan to operators. The build priority was communicated clearly through the card sequence from top to bottom, and the ahead/behind requirement is met by having the cards distributed throughout the day. It could be observed, for example, that the cell was keeping schedule if it were toured at 11am, and all cards had been flipped over through the 11 am time slot.

The second visual management system, however, had several shortcomings. Regarding the ahead/behind feature, it was still dependent on whether the operator walked to the board and flipped the card over upon completion of the operation. Second, both station 2 and station 3 actually consisted of two steps, and work in process inventory often waited between the two. These

cards were often prematurely flipped to signal the work was almost done, because there was no way to half-way flip a card. Also, operations tended to expand into the time slot allowed, such as a 20 minute operation consistently expanding to fill the 30 minute block.

Related to times expanding to fill the allotted time, there was even less processing time visibility. Operators were assigned stations, as recorded in the middle of the Daily Playbook, but it was not uncommon for operators to be assigned to multiple work stations. While the MES and all associated labor charging data could be queried to find out who did which operations, this information was not visual.

In contrast to Version 1, there was little visibility into product flow aside from stacks of parts between two sequential operations. Work in process inventory was only accurate, as recorded, once per day. Dependency between sequential operations was only communicated in verbal or written instructions to the respective operators, for example, when a particular unit had to be expedited through all the stations. Lastly, the only connection to MPS was the Two-Week Playbook, which only provided MPS connection at the end product level, not for subassemblies.

The visual management system was also missing clear-to-build functionality. While the Production Planner was performing clear-to-build checks with the site's ERP and MES systems, these activities were not visible to the production cell. Along this line, many in site management argued that this was solely a planning process and did not need to be recorded or reported to the production team. However, while the Planner, for the most part, stayed on top of longer-horizon parts issues, surprises were more frequent for in-house produced items.

The biggest risk was still that the Planner was responsible for controlling at each step how a subassembly progressed, i.e. into which end product configuration. The system was highly dependent on the Production Planner, meaning the plan had to be remade and cards rearranged at

each step whenever something interrupted production. When the Production Planner was sick, which happened on more than one occasion, frequent phone calls to the Planner's residence were required to keep production moving.

4.5 Enterprise Architecture #3

After six weeks of Version 2, it was determined that another attempt should be made at creating a "most complete" version of the visual management system to better suit all the enterprise value needs. Version 1 generally met specification, but its tedious and laborious nature, combined with the isolated way in which it was designed, made it an Enterprise Transformation failure. The stakeholders were not aligned and the end-users did not perceive the need. Version 2 was a quick compromise to meet the minimum Lean Culture Change Initiative phase gate requirements and remove all possible obstacles to planning and executing a recovery plan, but it contributed few of the sought-after enterprise values. It was resolved to try to create a system that synthesized the best of both systems.

The second reason was to improve total employee engagement. In both versions, front-line operator buy-in and commitment was lacking, and the management team felt including all stakeholders in the process would produce a more committed, unified group of system contributors. Since only a combined effort of operator, Planner, and management team could sustain the system, this buy-in was considered crucial.

To accomplish this, the entire production team and a number of other stakeholders participated in a multiple-day kaizen event, lasting a total of 6.5 clock hours. The list of stakeholders included the upstream, in-house circuit card department, other IPT Production Planners and operators, and the site's Lean Culture Change Initiative leader.

While the details of the kaizen process will not be discussed here, it is sufficient to say that the team reviewed ABSCompany's operational strategy, lean principles, Visual Management theory, and the advantages and disadvantages of previous systems, much as this thesis has done. The team identified a long list of features, shown in Table 8, which should be incorporated in Version 3 of the visual management system and brainstormed different system component possibilities. The kaizen team then combined different components to create Version 3, which consisted of a revised Two-Week Playbook, a revised Daily Playbook, a new team member role, and a plan to use an MES functionality previously overlooked.

Table 8: List of functions agreed upon which should be incorporated in the Version 3 system.

Requirements for new system
Planner/Planning
simpler, less manual planning
flexibility to change when something goes wrong
visibility of upstream / downstream issues communication between groups
status of intermediate test
Production Cell Visible Plan
plan vs. actual
by the hour (ahead/behind)
by builder
by all level of build (station 1, 2, & 3)
bottleneck process or area identification
process maps / diagrams for people, machines, and materials.
plan needs to show yesterday, today, and tomorrow
new system needs to tie to MPS
Past due needs to be visual
connection between levels and end unit req., "end product visibility"
space to comment on why takt is not met
time period accomodates operations of different duration
easy maintenance (to update, sustain, no errors)
easy for builders to contribute (min. extra movement, writing, etc..)
Clear-to-Build/Production Readiness
clear to build should be outside of cell plan, things on plan are clear
clear to build includes shop orders, parts, test software, layouts, engineering changes, etc.
need to see clear-to-build status for coming weeks
must look at all possible fires, not just the first one
Cell Inventory
proper amount of inventory in the cell
which parts need to be worked next.
Identification and segregation of defective material and scrap
Visual control of all required material (pull or kanban system).
wip visual at each station
1part-1place
Min-max
Counting either eliminated or made visual

4.5.1 Design Pilot, Implement, and Check Effectiveness

4.5.1.1 Design Pilot and Implement

The ERP and MES systems were to remain intact, but the kaizen event brought to light a feature of the MES which had not been considered before. The in-house circuit card assembly area, which was represented on the kaizen team, ran a very high mix of products through a number of machines, processing stations, and inspection areas. For production sequencing, circuit card team managers met every other day with IPT Production Planners to discuss which parts had to be expedited to enable production. Circuit card team managers then made respective adjustments to due dates, which, when entered into the site's MES system, changed priorities for subassemblies at various stations in the routings. By adjusting due dates in the system, the station processing and lead times backed out a prioritization of all circuit cards in each queue in the network of routings. An operator at each station simply needed to work against the queue in the MES system at the station's computer terminal.

It was determined that the Production Planner could simply adjust priority queues instead of rearranging cards on the Daily Playbook, relieving the requirement that the Daily Playbook be absolutely accurate as to what was processed at which times. As long as operators always completed the most urgent operation, namely those at the top of the MES queues, and did so to standard processing time, the production cell would make its overall production goal. This new control mechanism is shown highlighted in Figure 14. Thus, if the Planner had to make any urgent changes to the build plan, he just changed priorities in the MES, and the changes would be reflected the next time an operator transitioned to the next job at that station.
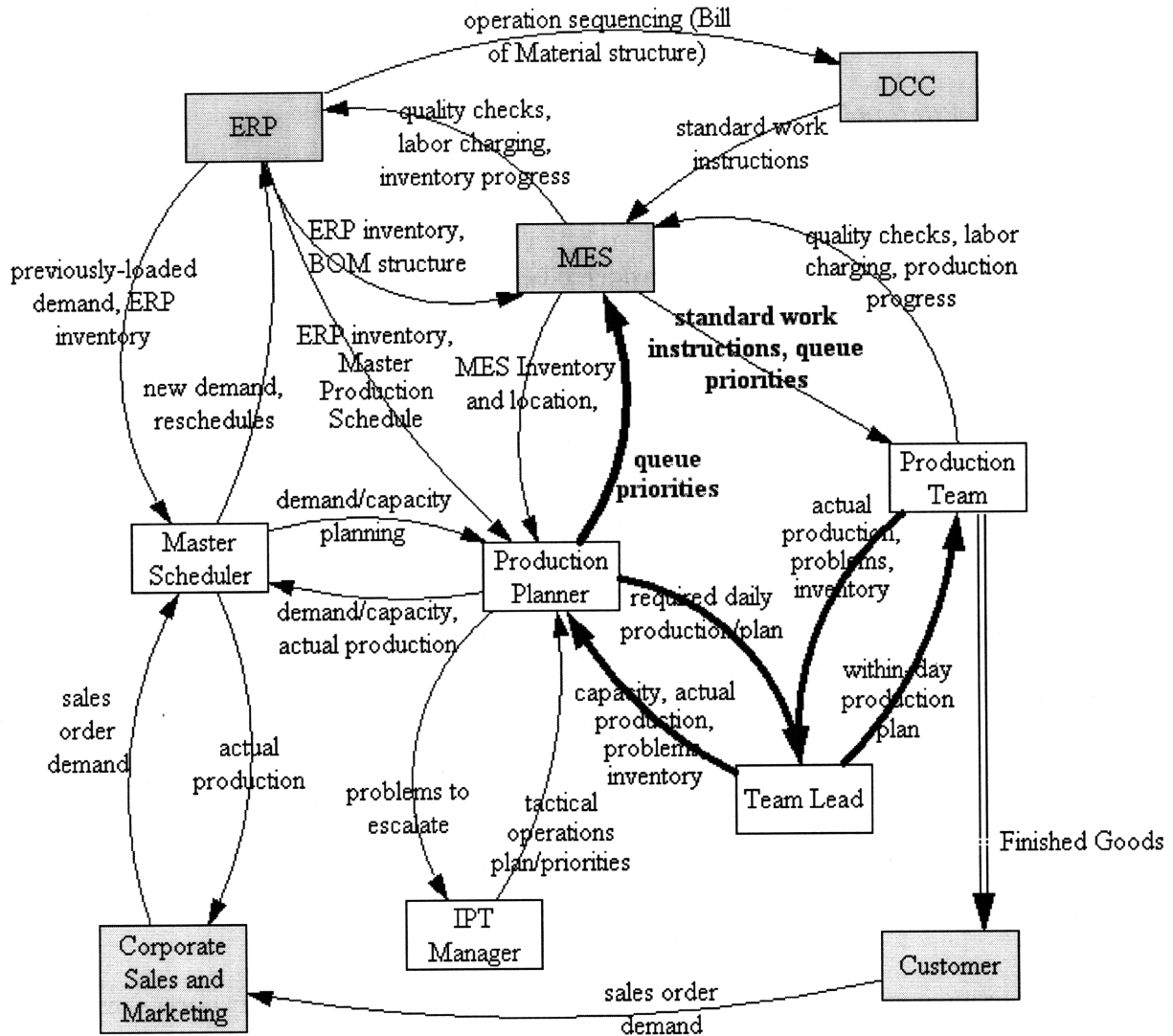
Figure 14: Enterprise Architecture #3 (Version 3) of information flows associated with production.

The Two-Week Playbook was revised to resemble Figure 15. The upper portion was changed to exhibit the clear-to-build status. This allowed the Planner to report daily how clear-to-build looked as much as seven weeks in the future. All possible reasons which would cause a line-stop were included in this itemized list, including standard work assembly instructions, engineering changes, circuit cards, etc. "MPS ship week" designation was added above each week, indicating to which ship week the MPS counts recorded below contributed. A few rows of critical subassemblies

were added below the MPS total row as a part of the clear-to-build process, which allowed inventory

on these items to be kept visual.

	Rolling 2-Week Playbook	People/Vacation:

Clear To Build	Week +1	Week +2	Week +3	Week +4	Week +5	Week +6	Week +7
	Source parts	Source parts	Source parts	Source parts	Source parts	Source parts	Source parts
	Make parts	Make parts	Make parts	Make parts	Make parts	Make parts	Make parts
	EO's	EO's	EO's	EO's	EO's	EO's	EO's
	NPI	NPI	NPI	NPI	NPI	NPI	NPI
	Tooling and Fixtures	Tooling and Fixtures	Tooling and Fixtures	Tooling and Fixtures	Tooling and Fixtures	Tooling and Fixtures	Tooling and Fixtures
	Test Software	Test Software	Test Software	Test Software	Test Software	Test Software	Test Software
	Layouts	Layouts	Layouts	Layouts	Layouts	Layouts	Layouts

MPS Ship Week

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.	Plan Act.

TOTAL

Delta

Issues

Figure 15: Version 3, Two-week Playbook. The latest version keeps track of production backlog as

before, but a forward-looking clear-to-build section keeps approaching supply chain issues visual,

and the production is linked to its corresponding MPS ship week.

The Daily Playbook was revised slightly, shown below in Figure 16. First of all, the inventory

was moved. A second day column was made for each side, allowing the Planner to post the next

day's schedule in the second column while retaining issues from that day's production until they

were discussed the next morning. Time blocks were divided into hour blocks, for simplicity, but the

cards themselves were scaled to lengths corresponding to actual build time, and the Velcro to which

they attached ran the length of the entire column instead of one short strip for each 30 minute block. For example, 3 20-minute cards could now fit in one hour block.

Date:	Station 2 Today	Comment Regarding Delays	Station 2 Tomorrow	Daily Playbook	Date:	Station 3 Today	Comment Regarding Delays	Station 3 Tomorrow
6am					6am			
7am				**Personnel Plan**	7am			
		Tier 2 Meeting					Tier 2 Meeting	
		Break		Water Spider			Break	
8am				Station 1, #1	8am			
				Station 1, #2				
				Station 2, #1				
				Station 2, #2				
				Load Unload				
9am				Station 3, #1	9am			
				Station 3, #2				
		Break					Break	
10am				**Station 1 Build Plan**	10am			
				assembly 1				
11am				assembly 2	11am			
				assembly 3				
				assembly 4				
12pm					12pm			
		Lunch		**Rework**			Lunch	
				Item / Fail Date / Location				
2pm					2pm			
		Tier 1 Meeting (break > 10 hours)					Tier 1 Meeting (break > 10 hours)	
3pm					3pm			
4pm					4pm			

Figure 16: Version 3, Daily Playbook. Only a few changes were made to the Version 2 board, such as adding a second day column to each side, the removal of WIP inventory area, and addition of a rework tracking section.

The Daily Playbook process was handled in much the same way as before. The Planner placed cards corresponding to a clear-to-build plan. When a job was completed, the card was flipped, but rather than each operator leaving his workbench at job completion to update the board, he recorded the job's completion time on a notepad located at each work station. This information was then transferred to the Daily Playbook by the help a "water spider", a new team role generated to support the system.

The water spider had several responsibilities. As mentioned above, the water spider transferred the team's task completion information to the Daily Playbook by flipping cards. The water spider was also responsible to collect parts from the parts crib, perform quality checks, and escalate issues to the Planner.

Another difference in the new system was the use of a 6-slot paper organizer at each station to keep each day's shop orders out in the open instead of centralized in a file cabinet at one end of the production cell. The sixth slot was held for those shop orders which had fallen past due, and management reviewed this daily.

4.5.1.2 Check Effectiveness

Using the MES system queues for shop order prioritization greatly simplified the demands of the visual management system, which could now occupy the role of reporting on the status of the system instead of also regulating production. The requirements of ABSCompany's Lean Culture Change Initiative were satisfied, and the team as a whole had reached a consensus which the individual team members were motivated to sustain.

Regarding fulfillment of each of the functions in Table 8, Version 3 met all the requirements, although some seemed more successful than others. Communicating the plan was done in a simple

manner with flexibility in exception cases. Plan vs. Actual and ahead/behind were apparent at a glance. Past dues were visible, both on the Two-Week Playbook and in the folders marked past due at each station's mini file organizer. It was easy for operators to contribute, because minimal extra movement and writing were required. Inventory levels were apparent at each station, and operators worked to keep work in process inventory within designated levels.

Space was allotted on the Daily Playbook according to standard processing times, but there was still some ambiguity, depending on whether there were one or two operators at a station. Once again, simplicity was the guiding factor here, and the consensus was that the card be trimmed to a two person length, and when only one was present, the cards was simply placed at double height.

One aspect which the author wished the system made more apparent was the ahead/behind or overall standard processing compliance by operator. In the initial system, an individual operator's contribution was observable by how many "done's" were recorded, and Version 1 addressed this by having each operator record the start and completion times of each task. In Version 3, when two operators were assigned to the same station, the individual contribution of each was indistinguishable. When one worked more efficiently than the other, it was not visually apparent, and there was no motivation for the slower one to pick up the pace.

Another requirement which was perceived as weaker in Version 3 was the connection to the Master Production Schedule at all levels of build, i.e. end product visibility. From earlier observations of "operational visibility", the author judged it important to be able to look at any piece of work in process and be able to quickly deduce which end product it corresponded to in the Master Production Schedule. Currently, the Planner must still act as the keeper of a switch-rail, choosing what a subassembly will "become" at each subsequent operation. Admittedly, it is the Planner's job to plan and provide a contingency when the supply chain is not operating smoothly,

but management muscle is being used where a well-functioning system should be. It can be argued that if parts are produced in house, as the ERP system is tasked with enabling, then a subassembly should be able to be pegged to an end product due in just four short operations. It should be noted, however, that while operational visibility may not have improved, MPS compliance, the more important of the two, did make progress.

Similarly, the clear-to-build process, while improved by addressing the broader supply chain for the advancing weeks, could still fall victim to within-the-week delays or "Just in Time failures". Currently, several parts have multiple storage locations throughout the cell, but a supermarket approach would satisfy the "1-piece, 1 place" requirement and make intra-week clear-to-build efforts more time efficient and less prone to surprises.

The final say whether Version 3 is a success or failure is the utility gained by the production cell, either by adhering to the system and improving it or abandoning it altogether. The real test will come when demand suddenly changes and supply chain issues once again take place, a condition which the author was not able to witness in the time before he concluded his internship and wrote this thesis. In contrast to Version 1, the Production Planner, production team, and IPT manager all invested heavily in Version 3. For this reason, Version 3 will likely succeed because end-users designed it, and it better utilized value proposition of MES.

4.6 Overall Case Study Results

The task undertaken was to design and implement a visual management system which would be used in conjunction with the ERP and MES systems employed at the production site. The case study at ABSCompany supported many of the theories presented in the literature review, and a number of insights were gained in the course. In the following two sections, conclusions are drawn

for Change Management and Visual Management, while broader Engineering Systems issues, such as IT architecture and Enterprise Architecting are covered in Section 0.0.

4.6.1 Change Management Takeaways

Fundamental to Janice Klein's Change Management theory is that true, sustainable change is pulled through the organization from a real need, challenge, or performance shortfall, which is normally perceived by some astute outsider-insider. In order for the proposed enterprise transformation to switch from push to pull, there has to be an agreed upon challenge or "burning platform". The site had none. In fact, the site was performing quite well, and the need for improving the initial visual management system was questioned, especially anything above the Lean Culture Change Initiative minimum. Many operators felt it was better the old way. The Production Planner and production team claimed to have no time to invest in designing a new system, but the real issue was likely that there was no perceived need to change. If the Planner had wanted to improve the status quo, time would have been made to do so. The visual management system was a perfect case of top-down push. The production team felt no ownership or responsibility. In this regard, the case study did not refute current Change Management theory.

For Kotter, creating this sense of urgency is the first step of Change Management. After all, can shop floor personnel really be expected to be able to recognize the challenge and perceive the performance gap between status quo and competitors, industry, or a new market reality? While the developing economic conditions certainly provided a good backdrop for the project, the team might have been more engaged if individuals were led to discover problems, challenge them, and find a better way. The reason why the kaizen process used to bring in Version 3 worked was it led the multiple-stakeholder team to discover and contribute to the process.

The challenge with having multiple stakeholders involved was controlling the scope and direction of the system design process. If too few stakeholders are represented, achieving buy-in from the remaining stakeholders will be challenging. If too many are involved, the result is either an impossible solution or a "Swiss army knife", which can do everything but is unable to do anything particularly well.

It was determined that a visual management system, as the object of the Change Management process, would only succeed if a critical mass of end-users support the underlying assumptions that 1) there are problems with the status quo and improvements to be made (micro pulls), 2) the visual management system will solve these problems, and 3)the benefits to the end-user outweigh the costs to the end-user. Even the production team kaizen event was management driven, which would indicate the change might face challenges ahead, unless the team is persuaded to trust the system will be beneficial until practice provides proof. Still, there must be not only system net benefit, but also every operator must in some way have a positive cost-benefit transaction, or the task will be neglected. This also supports the Change Management theory.

There is one last item regarding worker empowerment. Not only does "worker empowerment" have different connotations to different people, but the case study also showed that sometimes operators do not want to be empowered because of the added exposure to risk. For this reason, any proposed increase in empowerment must be weighed against the benefit the operator receives.

Much of successful Change Management is knowing when to push the issue and when to relent to the resistance. Klein suggests having end-users and other "front line" personnel create the system because they are familiar with the environment. The challenge for any change agent is to know when it is best to persist, persist, persist…or when to cut the line and regroup. For those situations

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where it is imperative that an initiative be implemented, even in spite of end-user resistance, micromanagement is needed to ensure that the push sticks.

Lastly, a change agent should never assume everyone is buying in just because they are going along with the program. Many are just going along with the flow, looking for the first signs of failure to justify abandoning the change having known all along it was not going to work. A good but risky exercise for any change agent who thinks a system has been adopted is to take the hands from the controls. Take a few days off or travel on business. If the end-users sustain the process and the system is still functioning upon return, the team has most likely genuinely accepted it.

4.6.2 Visual Management Takeaways

Regarding issues directly related to visual management, aside from the change process to implement it, the case study provided some useful insights. First of all, a visual management system should not just be a list of industry best practices, such as taped aisle ways or off-the-shelf kanban systems, but it should provide enterprise value not provided elsewhere. For example, it can be used to uncover inventory discrepancies "where the rubber hits the road", between ERP and actual production cell inventory. If done well, the system will react quickly to alert of any abnormality. Metrics boards act to align resource allocation at the micro level to those key process indicators deemed important at the strategic level. If it is decided that the visual management system should be used to directly regulate production, system designers should be careful that another system does not produce redundant and discrepant who, what, where, when, and how information.

On a very practical note, the best-designed systems are well thought-out and continuously improving, even iterative, after stakeholders have had a chance to try them out and discover unforeseen deficiencies. For this purpose it is important to get to a rough draft quickly, then refine.

Some people are naturally better critics than creators, so it can be beneficial to mobilize the power of feedback early in the design process.

Next, successful visual management systems are ones which require little-to-no writing, counting, or processing. In one sense, these are on-going "costs" of maintaining the system, and they are also a source of miscommunication and error. One reason why the Version 1 Daily Playbook board failed was its dependence on recording details. If a program could have been crafted to siphon actual processing time data and generate a report automatically, keeping standard processing time metrics would likely have stayed.

Lastly, a visual management system should be simple and intuitive. While a system can be large and provide massive amounts of useful data, often the simplest metrics like cumulative past due, can be the most effective. As Albert Einstein put it, "Everything should be as simple as possible, but no simpler."

4.6.3 Overall Visual Management Project Results

The visual management system is in use. Master Production Schedule compliance has improved by 50%. Work in Process Inventory was decreased to meet corporate targets. Lastly, productivity has increased by 30%, and there are fewer surprises through the improved clear-to-build system.

5 Conclusions and Recommendations

In the introduction it was hypothesized that visual management systems embedded in ERP and MES systems required certain conditions and support systems, or the visual management system could have adverse effects. This thesis set out to explore this and some of the fundamental issues around implementing both high-tech or low-tech visual management systems. To do so, the broader purpose of such systems was explored in context of the Enterprise Architecting framework.

5.1 Lessons Learned

The choice to implement an Enterprise Resource Planning (ERP) system is generally strategic in nature. ERP's are used because they are powerful, integrated databases, not because they are easy to use. They connect all functions, but they also force their logic and structure on business processes and usually exert almost imperceptible force on organizational structure. They coordinate material deliveries and stage production operations. An MES, on the other hand, is useful for delivering standard work instructions, labor charging, and recording quality checks. While both are necessary for production, their complicated software architectures can make determining production status elusive. For this reason, visual management systems, as an aspect of lean manufacturing, deliver a complementary enterprise value.

There are also synergies associated with integrating visual management systems with ERP and other IT systems. One synergy is that of enterprise control of inventory and supply chain while maintaining individual production cell ownership. In true enterprise fashion, upstream suppliers and downstream customers can be linked in the ERP system to provide better supply chain visibility. ERP facilitates data processing and production of reports, many of which are "push button", and these reports can ease the time requirements of producing metrics dashboards. The ERP can

remove the need to physically count inventory. Lastly, the awareness fostered through a visual management system enables improvement of all related enterprise metrics. Awareness causes improvement.

Integrating a visual management system with an ERP/MES system also has its issues. Even though the IT systems are enablers, for example, a performance dip usually accompanies every implementation. System incompatibilities usually plague such integrations, especially when the different systems have different upgrade time schedules. Next is if the two systems are necessarily "territorial", and system owners could begin hoarding information as a source of power. Third, even though the ERP can produce fabulous reports automatically, the metrics available for use in the visual management system are strongly influenced by what the ERP can easily deliver. If data acquisition and analysis is not electronic and "automatic" as at Raytheon, maintaining the visual management system will be an ongoing resource cost. This ongoing cost and engagement, on the other hand, can contribute to ownership and accountability.

System redundancy should be considered, as it can act both for and against the case to integrate visual management systems with ERP/MES systems. Redundancy, which is usually a good thing in engineered systems, means that when one system is down, the other is still operable and value-add production can continue. The counterpoint to the redundancy point made above is that when numbers do not match, significant efforts are required to audit, verify, and correct. For example, the two sources of production control in Version 1, i.e. the Production Planner and the Production Flow Kanban Board, gave conflicting messages at times. In these situations, system precedence must be established and procedures put in place to resolve discrepancies. For fully-integrated

electronic and automatic systems, if the ERP or MES system is down, the visual management system may be rendered useless.

5.2 Recommendations for Organizations and Practitioners

The enterprise value stream will in most cases determine whether the enterprise architecture should include an ERP or employ a simple, lean pull system, but in some cases, it is not an obvious decision. In general, an enterprise should be as simple as possible, making the lean pull system the first choice, especially for small-scale operations. A pull system is particularly suited for realized demand and simple, low part-count products or relatively inexpensive raw materials.

An ERP system should be used only when corporate strategy requires. ERP's are generally associated with push-type product situations, because of supply-chain lean time which precludes a pull system. ERP's are typically used in mature organizational settings which have process-oriented cultures capable of withstanding implementation. Similarly, complex, technological products with many parts from multiple sources typically require ERP-type management. Where nonconformance is significant and needs tracking, or where product pedigree needs tracking, an ERP system is almost always required. Lastly, if demand is shared between many facilities, an ERP is indispensible.

Occasionally, an ERP and MES are necessary to fulfill a company's overarching strategy, but production itself may be simpler than that which normally requires such IT functionality. For example, the ERP might be used to connect with customer demand, but the actual build process might consist of a few operations with a small number of inexpensive parts. In this case, visual management methods can be used.

When possible, use real, pulled demand, but forecast demand will also do. Allow the ERP to bring in materials as usual, which for simpler products could all be consumed same day, and release either a Type A or Type B kanban, depending on the product's architecture. At this point, the ERP disengages, and the pull system takes over. When product is complete and crosses the "finish line", whatever that might be, the ERP must be reengaged to cancel ERP demand and consume intermediate inventory. This process is commonly called "back flushing" demand. Periodic reviews of actual inventory will help keep the system reflecting reality, though accounting for scrap daily will help minimize frequency. There is also the option of using a push-pull boundary approach where relatively undifferentiated subassemblies are staged at a certain point in the middle of production operations, and realized, differentiated demand pulls from this stock to complete the product.

Use appropriate visual management methods to track products through routings. This can be accomplished through a closed-system approach for high volume cells (adherence to first-in-first-out principles and meticulous tracking of inputs/outputs). Product flow boards can be stimulated either manually, by operators moving magnets on whiteboard, or using entry and exit barcode scans to keep an electronic product status board current.

Certain conditions are requisite when visual management systems are to be embedded within a broader ERP/MES system. Purposes and domains are defined in terms of an enterprise value stream need, capabilities, constraints, and time domains. It should be determined, for example, whether the visual management system is to regulate production activities or just report metrics, as both have different implications on push-pull boundaries, the linkages, and interfaces. To review, some of the basic needs the visual management system should address are the following:

- Provides unambiguous who, what, where, when, how for production at the cell level

- Lend accountability and ownership to touch labor and immediate support staff

- Keep key process indicators visual, such as safety, quality, delivery, inventory, and cost

- Highlight abnormal conditions (right part-wrong place, wrong part-right place, missing part)

- Facilitate quick ahead/behind assessment for management pass-through inspection

Lastly, the push-pull analogy of lean to Change Management is an important consideration. Management can push change only so far. If a visual management system must be created, management should leverage the experience of its operators. Through a carefully-facilitated kaizen event, management can lead operators to discover the performance gap and reasons why reaching the goals of the top-down initiative would be beneficial to the operators. From there, end-user operators, who are better familiar with the intricacies of the production environment and process, can be counted on to create the appropriate system linkages, interfaces, and processes. The operators then become the system owners, linked and aligned to the enterprise strategy.

5.3   Recommendations for Future Research

One of the challenges of the visual management project at ABSCompany was being able to justify time spent by operators, either in brainstorming or focus group activities, to contribute to the visual management system. This resulted first from the difficulty quantifying the value gained by the company from a visual management system, especially when the visual management system could potentially contribute a range of values depending on chosen platform. Also, finding the optimal number and type of stakeholders was challenging. If too many attend, participants can tend to feel less control, obligation to contribute, and ownership. If too few attend, an elitist mentality could develop, or buy-in from the non-participating stakeholders will need to be earned. Lastly, every hour spent creating the visual management system must be weighed against its opportunity cost of

production time. A methodology for Change Management cost-benefit could be very helpful for management planning purposes.

Another area of research which this project uncovered is the process of production planning, and specifically, how the clear-to-build process could be captured and automated. While many programs likely exist to optimize production schedules, none could be found which worked with ERP systems to test proposed production schedules for supply-chain risk. Human-based production planning processes tend to focus on the most immediate emergency, neglecting to notice a looming future emergency. For example, if a critical part were held up due to a supply chain issue, normal ERP-driven supply chain materials would stack up, yet those parts on pull systems would maintain steady inventory levels, because they are not being pulled. As soon as the line-stopping part arrived, the line would process a few parts then stock out of the parts on the pull system, because the lead times cannot react quickly enough. If the production planning system or program could test various production plans for supply chain risk and expose dependencies and secondary risks, fewer line stoppages could result.

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