THE FACILITY RAMIFICATIONS OF IMPLEMENTING LEAN IN A BATCH MANUFACTURING PLANT

Brian C. Gutierrez[1] and Susan M. Bogus[2]

ABSTRACT

Lean manufacturing has revolutionized the manufacturing environment and its implementation requires a substantial modification of not only the manufacturing systems that govern the manufacturing process, but a physical transformation of the facilities where those manufacturing activities are taking place. Lean manufacturing principles such as elimination of non-value-added activities including material handling and storage require manufacturers to make substantial investments in their factories to reconfigure them for lean. Transforming a facility from a batch plant to a lean plant is an opportunity to introduce "lean synergy" where lean project delivery practices are used to create a lean manufacturing facility. A case study illustrates the use of these practices in a manufacturing setting.

KEY WORDS

Lean manufacturing, lean facilities, batch processing, product flow, lean synergy

INTRODUCTION

As lean manufacturing is implemented throughout the United States and around the world, a major challenge has emerged: how are facilities that were designed for batch manufacturing converted to facilities that are in line with lean manufacturing principles? These "monuments" to batch processing can be the buildings themselves or the specialized equipment contained within their walls. They were built with the idea that large product inventories are a good thing and are often organized by process rather than by product flow. Manufacturers are sometimes reluctant to make the necessary investment to modify existing infrastructure and instead implement lean processes only where they believe it is economical to do so, which then leads to a state which is a hybrid between lean and batch processing.

At their core, all lean processes follow the basic tenets of lean manufacturing, which include providing value to the customer, eliminating wasteful processing, and continuously seeking to improve those processes (Womack and Jones 1996). Because of the fundamental changes that must occur in product flow and therefore the physical environment to fully implement lean processes, the facilities where lean implementation is taking place must be configured to optimize this change of

[1] Graduate Student and Manufacturing Operations Engineer, Sandia National Laboratories, Neutron Generator Value Stream, PO Box 5800, MS 0873, Albuquerque, NM 87185-0873. Phone 505/284-6568, Fax 505/844-2128, Email: bcgutie@sandia.gov

[2] Assistant Professor, Dept. of Civil Engineering, Univ. of New Mexico, MSC01 1070, Albuquerque, NM 87131-0001. Phone 505/277-1395, Fax 505/277-1988, Email: sbogus@unm.edu (Corresponding Author)

paradigm. This often entails the removal of both literal and figurative walls to ensure that the processes are truly visible by all interested parties. The physical transformation of the infrastructure may require creative solutions to overcome a manufacturing legacy that was process centred rather than product centred. If the physical transformation of a batch plant is well thought out and adheres to lean principles, the psychological transformation of the end users may be facilitated.

The redesign and subsequent reconfiguration of these facilities provides an interesting opportunity to promote “lean synergy” which is created when lean project management methods are used in the construction or remodelling of a plant intended for lean manufacturing. This includes choosing the project delivery system that best fits into this lean paradigm.

This paper examines a case where facility modifications are being proposed and the challenges that are encountered. Aspects such as the open floor plan, modular utilities, adjacent office space, and visual communication are discussed, as well as, the types of project delivery systems and contracting methods proposed.

BACKGROUND

MOTIVATION

In the last decade, there has been a major shift in the manufacturing world from batch processing to manufacturing that follows the tenets of lean manufacturing that originated at Toyota (Nicholson 2006). Because of this paradigm shift, modifications to the infrastructure that supported the traditional methods of manufacturing are required. This includes tangible items such as utilities, layouts, and equipment and the less tangible such as organizational structure and worker responsibilities (Benjafaar, et al 2002). There is a substantial body of work that has addressed the general design of facilities such as Konz (1994), Lee (1996), and Heragu (2006), but none that focus on the specific transformation of a batch plant to a lean plant. Benjafaar et al (2002) focused on the evolution of factory layouts and suggests a solution for factories that have high product variety. A cursory discussion of lean facility design was conducted by Duggan (1998) in which he advocates for instituting the “adaptable value stream” within manufacturing cells, which can only be implemented if the facility has been designed to accommodate change.

As manufacturers transform batch plants to lean plants, there is an opportunity to promote “lean synergy” by also integrating lean project management into the overall process. Ballard and Howell (2003) introduce the components of lean project management in their Lean Project Delivery System Model. Lean project delivery applies lean philosophies to project definition, design, the supply chain, construction, and the occupancy of facilities. Their overview of lean project delivery includes a focus on the production system; transformation, flow and value goals; involving downstream players in the process early; consideration of project life cycle; and continuous learning throughout the process.

A model for “lean synergy” is created by extracting applicable ideas from these and other resources. Furthermore, by using a case study in which the conversion from batch to lean is in progress, the application of these ideas can be tested.

CONVERTING FROM BATCH TO LEAN

In order to understand the ramifications of going from batch to lean manufacturing, one must first understand the characteristics of each concept with regards to product processing. Batch refers to the manufacture of a product in groups of more than one and usually in quantities that are meant to take advantage of the concept of “economies of scale”. It is a common misconception that manufacturing efficiency is always increased by utilizing the maximum capacity of each piece of equipment regardless of the demand for the product (Duggan 1998). This creates unneeded inventory and an increased risk to product because of the additional handling required due to the need to store the excess production output and because an undiscovered quality issue may affect all previously processed inventory (Carreira 2005). A related problem is that often production equipment is specified and procured with incomplete information related to the actual eventual production needs and as a contingency is usually specified with excess capacity, rather than assuming the risk that equipment output would be inadequate. This usually leads to an underutilization of equipment or an excess amount of in-process or completed inventory, which is a fundamental violation of the tenets of lean.

Conversely, lean manufacturing promotes lot sizes that match up with demand, and in an ideal lean environment a lot size of one (Womack and Jones 1996). One-piece flow is the ideal situation because it keeps work-in-process (WIP) to a minimum, can help improve quality, and facilitates work balance (Lee 1996). This means that equipment can be properly sized to meet real demand, which then enables true product flow, another lean tenant (Womack and Jones 1996). If more capacity is needed in the future, additional equipment can be added, instead of paying for excess capacity upfront. In general, from a facilities standpoint, batch processing will require, larger and possibly more complex equipment, a larger footprint area, and will require more power and therefore larger utility services such as electrical, gas, chilled water, compressed air, etc. This will also make relocating equipment more complex and expensive. Lean facilities may be built to accommodate growth, but are designed such that equipment is properly sized, utility hook-ups are flexible and reconfigurable, and that reorganization of equipment and workstations is not only possible but also readily accomplishable (Benjafaar, et al 2002).

BATCH LAYOUT VERSUS LEAN LAYOUT

The most common traditional batch facility layout is a functional or process-based layout where like-processes are grouped and share the same location and resources (Heragu 2006). This works best in job-shop type of manufacturing where there may be high product variety or where production volumes are low. This type of processing has intrinsic liabilities when it comes to material handling because the product may leave and return to the same area several times because the layout is based on like processes and not the routing of the product. Furthermore, Heragu (2006) asserts that along with increased material-handling costs, there are corresponding increases in product cycle times, queue times, and complexity in planning and control. Another type of layout is product-based, in which the machines and workstations are located along the product route in order of production operations (Heragu 2006). The extreme of this type of layout would be the facility that is built around the product flow itself and would be continuous and linear where the product moves constantly from operation to operation, such as an assembly line. This is in the tradition of Henry Ford and may be appropriate for high volume, single product-type of manufacturing, such as automobiles.

The major drawback to this type of layout is that it creates difficulties when products are changed because of the product-specific layout (Benjafaar 2002). Lean manufacturing also focuses on the product routing itself and processes are set up with the intent of minimizing the amount of movement and handling that the product undergoes. One of the tenets of lean manufacturing is to eliminate non-value-added processing and since product movement does not add value to the product, it is considered waste (Womack and Jones 1996). Lean manufacturing also aspires to be flexible and agile so for most manufacturing a compromise between the two has been reached: cellular layouts (Carreira 2005). This type of layout involves using aspects of both product and process layouts in the form of "mini-factories" within the factory and allows for better manufacturing control by dividing one large system into several smaller sub-systems (Heragu 2006). Cellular layout works best when there is either a single product line or a family of products that share similar processing requirements. A conceptual illustration of the differences among product, process, and cellular layouts is shown in Figure 1.

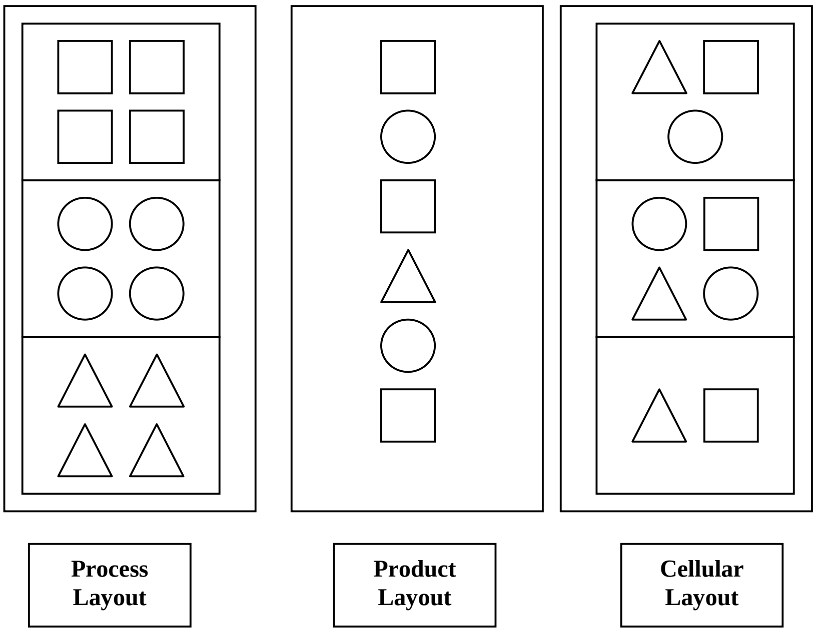

Figure 1: Conceptual Comparison Among Process, Product, and Cellular Layouts.

CHARACTERISTICS OF A LEAN SYNERGY PROCESS

When designing or re-configuring a manufacturing facility to incorporate lean tenets, an understanding of the potential impact of the lean ideals on certain facility characteristics and on the project delivery process must be understood. For example, lean manufacturing espouses the virtue of minimizing material handling. A corresponding facility ramification would be the need to configure the factory with process adjacency in mind so that product is immediately and readily passed on to the succeeding operation. In project delivery, a construction ramification would be a focus on material staging to minimize handling. Another example would be the importance that lean manufacturing places on communication and information exchange among all participants in the manufacturing process such as operators, process engineers, supervisors, managers, etc. An important facility consideration that would address this issue would be a facility that includes an open floor-plan. Furthermore, it would be important to have a layout where production areas are adjacent or at least proximate to process control personnel offices, which would then facilitate operator and process control personnel interaction and in turn encourage a swift resolution to production issues. Another facility issue that affects communication, and is often overlooked, is procuring equipment that is quiet enough to have a conversation around without having to shout (Duggan 1998). In project delivery, communication among the owner, designer, and builder could be improved by using a design-build project delivery system, where the designer and builder are part of the same team, thus allowing the builder to participate actively early in the design process. Another way to improve communication during project delivery is to co-locate staff from the owner, designer, and builder near the project site. Construction equipment manufacturers are also taking note of the issues that noisy equipment creates.

Some of the facility characteristics that have high potential impact on the implementation of lean include:

- *Engineered controls*: controls that have intrinsic properties in their design to prevent human error
- *Modular equipment*: equipment that is designed to be easily relocated
- *Modular utilities:* utilities that are designed to provide flexibility when reconfiguring equipment layout
- *Open floor plan*: production areas that are openly visible either through the use of open areas or through the use of glass walls
- *Process adjacency*: the desire to have processes that are adjacent to the succeeding process
- *Process control adjacency:* the desire to have process control personnel proximate to the production area
- *Right-sized equipment*: equipment that is specified to match production output
- *Visual workspace*: production areas that use visual queues to facilitate production operations

Table 1 provides a summary of lean tenets and the corresponding facility and project delivery characteristics that have been compiled from concepts in Benjafaar, et al (2002), Carreira (2005), Duggan (1998), Heragu (2006), Hinckley (2001), Konz (1993), Lee (1996), Ballard and Howell (2003), Koskela et al. (2002), Freire and Alarcon (2002), and Womack and Jones (1996).

Table 1: List of Lean Manufacturing Characteristics and Corresponding Facility and Project Delivery Characteristics.

Lean Characteristic	Corresponding Facility Characteristic(s)	Lean Project Delivery Approach(es)
build in quality	process adjacency, visual workspace	co-locating staff, qualification-based selection, life-cycle design
eliminate bottlenecks	modular equipment	supply chain management, modular equipment, flexible crews, Last Planner
encourage proper maintenance	right sized equipment	right sized equipment
facilitate communication	open floor plan, process control proximity	electronic documents, co-locating staff
facilitate information exchange	open floor plan, process control proximity	electronic documents, co-locating staff
facilitate process flow	process adjacency, right-sized equipment	production planning, Last Planner
incorporate safety and security measures	engineered controls	on-site safety and security personnel
match lot size to demand	right-sized equipment	small design packages, right sized equipment, flexible crews
minimize material handling	process adjacency, right-sized equipment	electronic documents, material staging plan
mistake-proofing	engineered controls	quality improvement program
reduction of cycle time	process adjacency, right-sized equipment	concurrent engineering, design-build delivery
standardization	modular utilities	modular construction, prefabrication
utilize labour efficiently	modular equipment, process adjacency	prefabrication, production planning, flexible crews
utilize space efficiently	right-sized equipment, process adjacency	right sized equipment, site planning

CASE STUDY

NEUTRON GENERATOR PRODUCTION

Neutron generators are miniaturized linear particle accelerators used in nuclear weapons and require specialized equipment and processes to produce. In 1993, the Department of Energy decided to close its neutron generator production facility, Pinellas Plant, located in Largo, Florida, and relocate it to Sandia National Laboratories in Albuquerque, New Mexico as a cost-savings measure and to locate it at the site where neutron generator design took place. A new facility was designed and built with the input of many of its end-users. This lead to a compartmentalized building where most everything is grouped by process and little or no regard was given to the product flow. Processes such as cleaning, metalizing, plating, brazing, welding, evaporation, and optical gauging were all given their separate areas.

The idea was to create a building that housed both production and development activities in the same complex and utilized the same equipment. Because of increased demand, a decision was made in 2000 to implement lean manufacturing methods to increase efficiency and to separate production and development activities. Implementing some components of lean such as identifying the value stream, implementing a pull system, and training personnel in lean were readily accomplishable, but other aspects of lean that required layout reconfiguration were not. Unfortunately, because the layout of the factory was fixed and it was cost prohibitive to reconfigure, the ability to create a complete lean environment was impossible, at that time. Figure 2 shows an illustration of the movement necessary for one subcomponent within the manufacturing floor to be completed, as well as an illustration of the ideal state of the same manufacturing floor. Because there are fixed utilities, structural walls, and special venting systems, reconfiguring the layout is difficult, therefore achieving the ideal state in this situation would be cost prohibitive.

Using a Pareto analysis of those areas where facility constraints are most hindering the implementation of lean manufacturing, a comprehensive plan was created to gradually reconfigure the facility by tackling those areas that have the greatest potential for return on the investment. An intimate knowledge of the value stream is necessary to do this because when implementing these changes piecemeal, the effects on upstream and downstream operations must be taken into consideration. Currently, a plan has been formed to modify the layout of the plant as equipment is replaced. The first step identified will be the replacement of large stationary hydrogen furnaces with smaller modular furnaces that will be used for smaller lots, occupy less space, and which have the ability to be relocated, if necessary. When layouts are changed, a desire to utilize designers and contractors that understand and use the concepts of lean in their own project realization has been discussed in order to ensure that all aspects of the redesign meet lean standards.

LEAN OPPORTUNITIES IN PROJECT DELIVERY

Sandia National Laboratories has a complicated construction procurement process due to the fact that it is owned by the Department of Energy, while Lockheed Martin, a private corporation, operates it. This means that it is subject to many of the procurement constraints that any public entity is subject to, which therefore makes it more difficult for the use of innovative project delivery systems. Because the neutron generator facility is considered a “Customer Funded Project” from the perspective of Sandia, it has in place a fixed process that must be followed for procuring construction. This limits the ability to use most any other project delivery system other than design-bid-build. It is the intent of the neutron generator production facility to challenge the status quo and propose the use of lean initiatives for future renovations. For example, for the reconfiguration of the hydrogen furnace area, it is necessary to continue production operations, so a “modular” or phased project delivery approach is the most appropriate. This is an example of “right sizing” the project delivery to facilitate flow and eliminate buffers. Another lean project delivery approach planned for this project is co-locating owner, designer, and builder staff in one location to facilitate communication and improve quality.

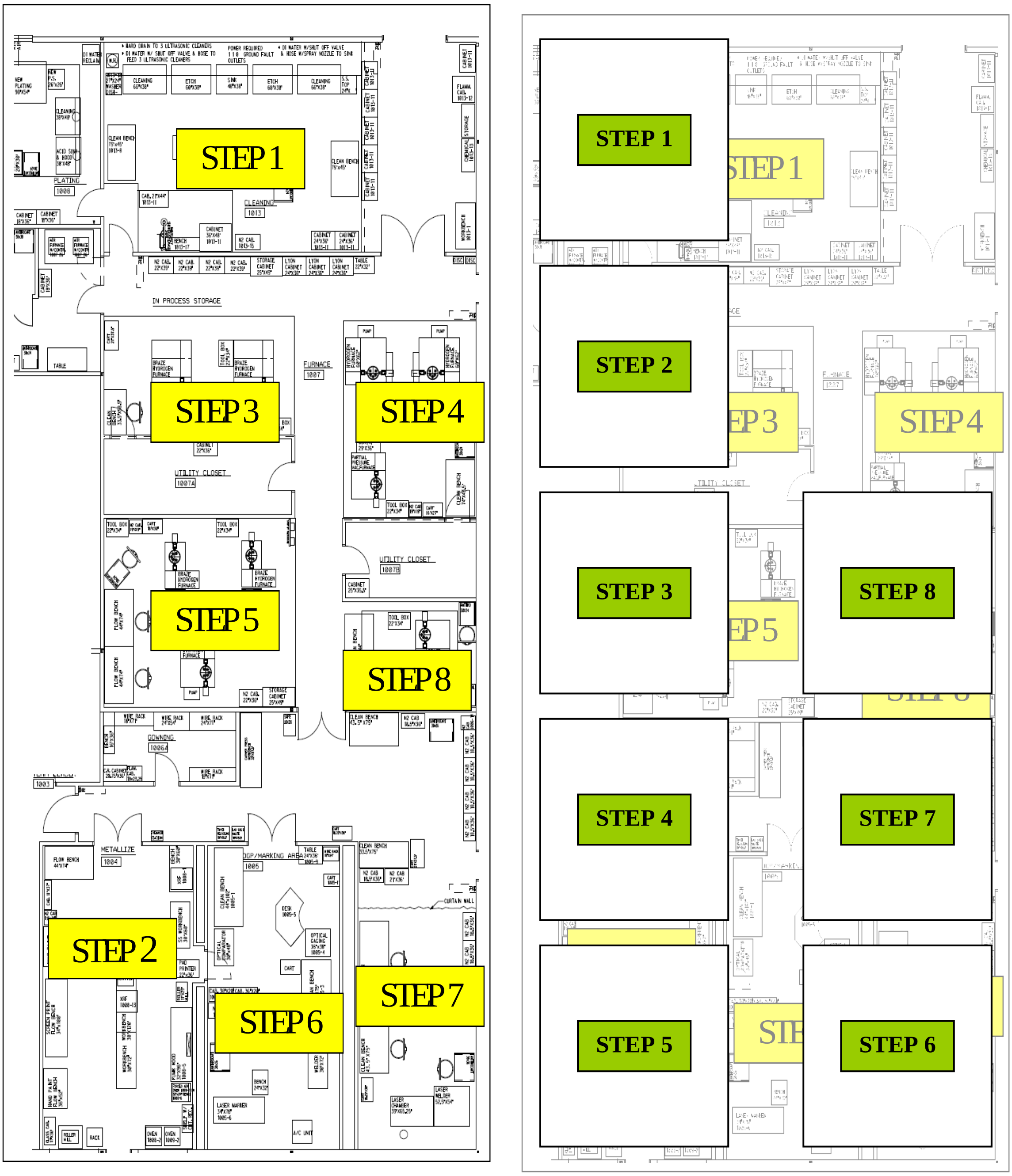

Figure 2: Current Production Movement (l) and the Ideal Movement with Process Adjacency (r)

CONCLUSION

Facility transformation of any kind can be a daunting task because of the constraints that are created when designs are produced with a certain paradigm in mind. This is especially the case for batch manufacturing plants because fixed infrastructure complicates the ability to reconfigure layouts and since much of lean manufacturing depends on the ability to transform production areas, an impasse is reached. With unlimited resources, the ideal situation is to begin from scratch and include the lean paradigm in the initial design because then the flexibility is built into the factory. If a facility already exists, then a comprehensive reconfiguration to include those attributes that make lean manufacturing easily implementable should be undertaken. In this case, it would be prudent to utilize design and construction firms that are at least familiar with lean, or preferably that utilize lean concepts to realize their projects. Unfortunately, financial constraints do not always allow for this type of major investment and a phased approach to implementing lean facility characteristics must be used. Once the transformation begins, with every successive facility modification that takes place to transform a factory from batch to lean, it brings the whole facility closer to becoming a fully lean facility. This modular, phased approach to facility modification is being adopted by Sandia National Laboratories. The success of their approach is still being studied, but the use of lean project delivery practices as part of their transformation to lean manufacturing creates a “lean synergy” that can benefit the entire project.

REFERENCES

Ballard, G. and Howell, G.A. (2003). “Lean Project Management.” *Building Research & Information*, 31(2), 119-133.

Benjafaar, G., Heragu, S., and Irani, S. (2002). “Next Generation Factory Layouts: Research Challenges and Recent Progress”

Carreira, B. (2005). *Lean Manufacturing that Works,* American Management Association, New York.

Dorf, R., and Kusiak, A. (1994). *Handbook of Design, Manufacturing and Automation*, Wiley, New York.

Duggan, K. (1998). “Facilities Design for Lean Manufacturing.” *IIE Solutions*, December 1998.

Freire, J. and Alarcon, L.F. (2002). “Achieving Lean Design Processes: Improvement Methodology.” *Journal of Const. Engr. And Mgt.*, 128(3), 248-256.

Heragu, S. (2006). *Facilities Design*, Universe, Inc., New York.

Hinckley, C. (2001). *Make No Mistake!,* Productivity Press, Portland.

Konz, S. (1993). *Facility Design*, Publishing Horizons, Scottsdale.

Koskela, L., Huovila, P., and Leinonen, J. (2002). “Design Management in Building Construction: From Theory to Practice.” *Journal of Const. Res.*, 3(1), 1-16.

Lee, Q. (1996). *Facilities and Workplace Design*, Engineering and Management Press, Norcross, Georgia.

Nicholson, T. (2006). "Owners Seek Lean, Flexible Facilities in Consumer Demand-Driven Sector." *Engineering News Record*, 256(25A) 54-56, July 2006.

Womack, J., and Jones, D. (1996). *Lean Thinking*, Simon and Schuster, New York.