Virtual Shop Clusters – A New Layout Concept for a Ship Repair and Maintenance Facility

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Abstract

This pilot project assessed the feasibility of Cellular Manufacturing at a ship maintenance facility. Using the PFAST software, several potential families of repair jobs, and the appropriate cluster of shops for each family, were identified. Based on these results, it was decided to implement a Focused Factory to complete any repair job done by the Dive Shop. The Dive Shop would be merged with other support shops, and be provided the necessary tools, cross-trained personnel, etc. to become an autonomous multi-function shop. In addition the advantages of implementing a Virtual Shop Cluster in a ship maintenance facility were assessed.

Keywords  
JobshopLean, Ship Repair Maintenance Facility, Simulation, Flow Analysis, Focused Factory, Virtual Shop Cluster

1. Introduction

The Southeast Regional Maintenance Center (SERMC) is a ship maintenance facility that repairs large ship parts. It is a guild-type facility because the type of work done in each shop is based around a skill (or skill set) and carries equipment with the same (or similar) process capabilities. In essence, the layout of the SERMC facility corresponds to a Process Layout. ex. welders are in the Weld Shop, machinists are in the Machine Shop, pipe-fitters are in the Pipe Shop (see Figure 1). Therefore, a single shop usually does not complete any repair job. Since each job needs multiple steps/tasks that get done in multiple shops, sometimes involving multiple visits to the same shop, the flows of numerous active jobs between the different shops results in significant amounts of the Eight Types of Waste, especially transportation, queuing, inventory, and operator motion. In turn, these wastes translate into high operating costs and extended lead times for order completion.

There is a belief that this guild-type organizational structure is what enables a repair facility to do almost anything, albeit at the cost of moving product all over the "factory". This organizational structure is identical to the Functional (or Department) Layout that is preferred by most Jobshops. But, any company that has successfully implemented Lean Thinking has almost always replaced a Functional (or Process Village) Layout by a Cellular Layout.

1. JobshopLean

The ideas, methods and tools of the Toyota Production System aka “ToyotaLean” or “Lean Thinking” are best suited for low-variety high-volume facilities with stable demand. Therefore, an MRO ship maintenance facility like SERMC is better served by the ideas, methods and tools of “JobshopLean” which was developed for high-variety low-volume facilities. Examples of commercial facilities that are jobshops are collision repair shops, tool and die shops, machine shops, etc. SERMC already has shops, such as Pipe Shop, Machine Shop, Sheetmetal Shop, Pump Shop and Valve Shop that qualify as jobshops!

JobshopLean is founded on the following fact: Given a poorly-designed facility layout, the Average Travel Distance for any order ↑ therefore Waste of Transportation ↑ therefore Waste of Work-In-Process Inventory ↑ therefore Waste of Waiting ↑ therefore Ship-To-Ship Job Flow Time ↑, Throughput ↓ and Job Completion Cost ↑.
Cellular Manufacturing is a key element in the JobshopLean strategy. A Cellular Layout (see Figure 1) is a network of several independent groups (or cells). Each cell is a group of dissimilar machines with different process/functional capabilities that are collocated in an area of the shopfloor. Each cell is dedicated to manufacture a family of parts i.e. the parts (or products) have identical (or similar) routings, tooling, materials, and other requirements. Conversion of an existing Process Layout to a Cellular Layout requires significant capital investment. Therefore, this layout is best suited to a greenfield project where a new facility is being built and the equipment locations can be optimized at the outset during the design/blueprint phase.

A complete conversion of an existing shipyard, especially a non-production MRO facility like SERMC, from its existing guild-type shop structure to a Cellular Layout was ruled out. Therefore, two alternative layouts that are extensions of the basic concepts of Cellular Manufacturing – Focused Factories and Virtual Cells – were considered next. Focused Factories are the co-location of a group of shops in one area (Manufacturing Cell). Plants are established to focus the entire manufacturing system on a limited, concise, manageable set of products, technologies, volumes, and markets precisely defined by the company’s strategy, its technology, and economics. They create a single shop with multiple skill sets to handle a group of jobs. Some of the benefits of Focused Factories are reduced delays (communications and queuing) and wastes (transportation, inventory, operator motion, etc.). Unfortunately, the implementation of a Focused Factory could still require re-layout of an existing facility and the new layout could still be inflexible to changes in mix, volume and demand stability.

Virtual Cells relax the co-location requirements for machines that are grouped into Physical Cells, i.e. the machines in a cell that can process a family of parts are not co-located; instead their setups, tooling, etc. are “virtually dedicated” to make only the parts in the family that is assigned to the cell (see Figure 1). Communications between the machines and supporting resources, such as material handlers, that comprise any Virtual Cell must be JIT. This can be achieved using electronic communications, WAD (Wide Area Displays), obstruction-free material handling aisles with line-of-sight between workcenters, etc. Some of the benefits of Virtual Cells, such as reduced delays (communications and queuing), are the same as those of a Focused Factory. Unfortunately, unlike Physical Cells, Virtual Cells could not reduce the wastes of transportation, inventory and operator motion. Fortunately, unlike Focused Factories and Physical Cells, capital investment for implementation of Virtual Cells is significantly lower. Since the existing Process Layout is retained to some extent, a Virtual Cellular Layout possesses the greatest flexibility to accommodate changes in mix, volume and demand stability.

2. Pre-project Analysis

The pilot project at SERMC sought to evaluate whether both extensions of the basic concept of Cellular Manufacturing – Focused Factory and Virtual Cells – had merit and would facilitate the implementation of JobshopLean in any Navy MRO facility with a similar operational structure. Therefore, to design a Focused Factory and/or a Virtual Cell, it was necessary to identify groups of shops that processed families of repair jobs. In the Current State at SERMC, there are Lead Work Centers (LWC) that are connected to different Assist Work Centers (AWC) by four different types of material flows:

- Equipment
- People (skills & support)
- Materials & machines
- Information (Communications, Knowledge and Decisions)
Information flows were supported by four types of inter-shop communications:

- Phone
- Email
- One-on-one meetings among individuals
- Daily production meetings (sometimes followed by additional meetings among personnel in the same shop)

These information flows helped the LWC’s to keep in contact with their AWC’s. Since information flows are a prerequisite for material flows, the existing modes for information flows adversely impacted the communication flows which, in turn, caused waste (queuing, transportation, operator motion, setup, etc.) and scheduling delays. Ultimately, this translated into high operating costs and extended lead times for order completion.

Data collection began with an effort to identify the high priority jobs (also referred to as CASREP’s, or Casualty Reports) that were closed during the period 10/05-5/06. Typical data that was collected for each job was the LWC and AWC’s involved, the frequency of occurrence of this job during the performance period, the typical sequence in which the AWC’s were visited prior to the job arriving at the LWC to be completed, and the type/s of interactions between the various work centers (equipment, people, materials and information). After the three input files for the PFAST software were processed, PFAST generated a variety of outputs that helped to identify key areas for improvement opportunities. Initially a Q-type Flow Diagram was produced and showed heavy material flows between a cluster of shops with the Dive Shop as the centroid of the cluster. This was the first indication that a Focused Factory which brought together the Dive Shop and its key AWC’s was a viable option for Cellular Manufacturing at SERMC.

Two other PFAST outputs that were used during this Design→Analyze phase of the project are P-Q-S Analysis and P-R Analysis Type I (see Figure 2). P-Q-S Analysis, which is an extension of the typical P-Q Analysis (or Product-Quantity Analysis) considers the Volume and the Value (measured by Revenue) of any repair job. For example, a repair job that belongs in the High-Volume High-Revenue quadrant of the scatter plot merits top priority during kaizen events to reduce the wastes, costs and delays in their Value Streams, instead of the Low-Volume Low-Revenue repair jobs. A significant flaw in the “Lean Toolkit” used by Lean traditionalists trained in the Toyota philosophy is that low-volume jobs can be profitable for a high-mix low-volume jobshop!

P-R Analysis Type I (see Figure 2) uses a 0-1 matrix to identify the relationships between all shops that are used to process various CASREP’s. In this matrix, each “1” at the intersection of a row and column indicates that the CASREP represented by that row of the matrix has work done on it in the Shop represented by that column in the matrix. PFAST reorganizes this initial matrix to produce the final matrix shown in Figure 2. Clusters (or blocks) of 1’s in the matrix correspond to families of CASREP’s that could potentially be produced by a Shop Cluster (or Cell) or Focused Factory if the necessary equipment, manpower and support services/resources could be fully dedicated to that area.

Figure 2 demonstrates a novel method (P-Q-R-S Analysis) since it combines P-Q-S Analysis and P-R Analysis Type I. In order to differentiate the CASREP’s by their relative importance to SERMC, they are color-coded as follows:

- Green = High-Volume, High-Revenue
- Yellow = High-Volume, Low-Revenue or Low-Volume, High-Revenue
- Red = Low-Volume, Low-Revenue

Cells and Focused Factories are most effective when designed to produce product families that are profitable with stable volume of work. Therefore, in Figure 2, the clusters of rows that are mostly colored green are the best candidates for implementing a cluster of shops that could be grouped and managed either as Physical or Virtual Cells. Figure 2 gave further indication that a Focused Factory which brought together the Dive Shop and its key AWC’s was a viable option for Cellular Manufacturing at SERMC.
Additional visualizations helped to capture the considerable inter-shop flow delays and operational wastes in the Current State of the SERMC facility. Flow charts to distinguish the high-volume inter-shop flows and also types of communication in inter-shop flows of CASREP’s were used. Both clearly supported the original hypothesis for this pilot project, that the current guild-type organization of SERMC is a primary contributor to their high operating costs and extended lead times for order completion. In particular, the opportunity cost due to the low value-added utilization of the workforce is significant since much of their time is consumed by the delays and wastes that are the direct result of the large distances separating shops that should either be combined or located adjacent to each other.

The shops in the SERMC facility are currently grouped into four Branches (Hull, Auxiliaries, MP&E, Services). Cells and Focused Factories implemented based on the clusters of shops identified in Figure 2 offer a radically different concept for grouping the existing shops. Figure 3 helps to visualize and compare the inter-branch flows (shown as Red lines) compared to intra-branch flows (shown as Yellow lines). The Future State can be compared to the Current State with line colors changed appropriately, where the physical or virtual groups of shop clusters created from P-R Analysis Type I (see Figure 2) replace the previous four Branches. Figure 3 clearly demonstrates the significant reduction in flow delays and operational wastes to be gained by reconstituting the four branches.

Figure 4, which extends the analysis in Figure 3, presents a unique approach to waste analysis using a Q-type From-To Chart. This chart records the inter-shop flows between any and all pairs of shops required by various CASREP’s. The key difference between the Current State and the Future State is that the shops clustered into Branches are
different in both states. Consequently, the intra-branch and inter-branch flows will differ in the Current and proposed Future State. By reconstituting the shops contained in each Branch, the speed and effectiveness of interactions between any two shops could improve or worsen, depending on whether they were assigned into the same shop cluster or different shop clusters, respectively. Yellow boxes represent maintained intra-shop connections after the reconstitution, green boxes and red boxes represent gained and lost connections respectively. It was decided to use the ratio of inter-branch to intra-branch connections as a measure of flow efficiency and waste reduction. Ratios for the Current and Future State are 21% and 46% respectively. According to the Future State, without considering shops in the Services/Ships Branch, savings of 82.9% wasteful communications could be achieved.

![Figure 4 Waste Analysis –Future State respectively](image)

4. Focused Factory for Dive Shop

Due to budget shortfalls, a decision was made by the Navy to reduce military personnel at the Regional Maintenance Centers, primarily involving the military in the Production Department. Because this effort would reduce the amount of work performed in-house and shift a lot of the work to local ship repair contractors, the implementation of Virtual Shop Clusters was deemed infeasible. The focus of the project was shifted to the Dive Shop, specifically to the implementation of a Focused Factory. A detailed review of the nature of work done in this area, and the Quantity-Revenue statistics for those CASREP’s, it was clear that most work (approximately 60%) consisted of Valve and Pump jobs. Therefore, a decision was taken to implement a Focused Factory with the Dive Shop at its core by absorbing resources and personnel from other shops. Thereby, a Dive/Pump/Valve repair job that earlier visited multiple shops, which involved multiple handoffs between shops, could now have all of the steps in that process done in a single shop capable of handling all aspects of that family of repair jobs.

In general, there are three major steps required to complete a typical Dive/Pump/Valve job: Remove (Paperwork, Dam, Transportation), Perform repair work, and Replace (Paperwork, Dam, Transportation). Currently a Dive/Pump/Valve Job requires 13 passes in 15 steps between various shops including Dive, Valve or Pump, Riggers, Inside Machine, and Outside Electric. The ideal self-sufficient Focused Factory would completely eliminate the passes between shops for the entire process. To do this the Dive Shop would have to be responsible for all of the steps in the process. However, Pump/Valve repair is very knowledge-intensive and it would be hard to cross-train the operators. Besides, this step can also take several days; so there is already a fair amount of waste associated with this step. Therefore, it was decided that the Dive Shop Focused Factory would be responsible for all the steps in the Current Process Flow except for the actual repair of the Pump/Valve.

The future process will still have 15 steps but only 2 inter-shop passes from the Dive Shop to the Pump/Valve Shop and back. There was the possibility that the Navy would contract more work out due to the reduction of SERMC staffing levels. Hence, this new shop configuration would allow for the possibility of Pump/Valve repair to be contracted out but allows SERMC to still have control of the removal and replacement of the pump/valve.
5. Simulation
The goal of the simulation was to create models of inter-shop flows in the Current State, and the Future State, to prove the possible gains by implementing Physical or Virtual Clusters to partially replace the current Functional Layout at SERMC. The simulation of the Current State created a process box for every step required by a job going through the Dive Shop. Each step had a delay equivalent to the setup and process time for that step. The appropriate number of resources was also required to be at those steps for the delay, equivalent to the work content for that step.

Resources represented the shops. The resources assigned to a particular shop would perform only the tasks assigned to that shop. In addition, to appropriately account for communication and transportation delays, resources were held (locked) to a job until they could find a resource from the destination shop to hand the job off to. If the job was just moving inside the shop, then these delays would not be incurred and an immediate handoff would take place. This is where the co-location of shops and conversion of inter-branch flows to intra-branch flows by revising the shop compositions of the existing Branches is extremely beneficial.

For the simulation of the Future State, process boxes were created to include the new jobs that the Dive Shop would be processing. Sorting repairs at the beginning of a job and running them through a simpler process resulted in a much less chaotic and congested flow network. The processes were created so that the Dive Shop resources could cover these steps instead of external resources in the Pump or Valve shops.

The simulation results showed that implementation of the Physical or Virtual Shop Clusters would decrease inter-shop flows, decrease non-value-added times for all the processes and jobs, decrease waiting and communication delays at each shop, and increase shop efficiencies and decrease the average flow time for any repair job. In addition, the more obvious impact on transportation and operation motion wastes due to co-location of several shops in a Physical Shop Cluster was verified. There was over a 100% increase in pump and valve jobs completed. Lead times and cycle times dropped approximately 33% and 50% respectively.

6. Conclusion
All in all, the project produced many options with some of the more viable and effective including u-shaped shop clusters, outsourcing, tuggers (water striders that run timed routes to transport resources to various locations), action boards (visual displays for passerby’s to see current shop schedules and conditions), and facility re-layout. The success of this pilot JobshopLean project which proved the viability of implementing the Dive Shop Focused Factory in a high-mix low-volume repair jobshop like SERMC is encouraging. It is recommended that the same idea be tested at other Navy Fleet Maintenance Facilities. Given the age of most of these facilities, one can expect that almost all of them are organized as trade-specific shops. Virtual Shop Clusters supported by 21st technology for distributed teaming, mobile computing, etc. could be the next frontier for Lean Thinking!

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