PERGAMON

Robotics and Computer Integrated Manufacturing 18 (2002) 255–265

Robotics and Computer Integrated Manufacturing

www.elsevier.com/locate/rcim

Equipment replacement decisions and lean manufacturing

William G. Sullivan, Thomas N. McDonald, Eileen M. Van Aken

Grado Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Abstract

Traditional manufacturing systems are built on the principle of economies of scale. Here, the large fixed costs of production are depreciation-intensive because of huge capital investments made in high-volume operations. These fixed costs are spread over large production batch sizes in an effort to minimize the total unit costs of owning and operating the manufacturing system. As an alternative to "batch-and-queue," high-volume, and inflexible operations, the principles of the Toyota Production System (TPS) and lean manufacturing have been widely adopted in recent years in the US [1–4]. In this paper, we illustrate an equipment replacement decision problem within the context of lean manufacturing implementation. In particular, we demonstrate how the value stream mapping (VSM) suite of tools can be used to map the current state of a production line and design a desired future state. Further, we provide a roadmap for how VSM can provide necessary information for analysis of equipment replacement decision problems encountered in lean manufacturing implementation.

Keywords: Lean production; Equipment replacement; Cellular manufacturing; Value stream mapping

1. Introduction

Traditional manufacturing systems are built on the principle of economies of scale. Here, the large fixed costs of production are depreciation-intensive because of huge capital investments made in high-volume operations. These fixed costs are spread over large production batch sizes in an effort to minimize the total unit costs of owning and operating the manufacturing system. Large work-in-process inventories are also characteristic of traditional manufacturing. The resultant "batch and queue" operation produces large numbers of a particular product and then shifts sequentially to other mass-produced products.

As an alternative to batch-and-queue, high-volume, and inflexible operations, the principles of the Toyota Production System (TPS) have been widely adopted in recent years throughout the US [1–4]. Application of TPS principles have led to lean manufacturing (also called lean production, or lean thinking [4]) in which production and assembly cells consisting of product-focused resources (workers, machines, floor space, etc.) are closely linked in terms of their throughput times and inventory control. These cells are typically U-shaped or rectangular and lend themselves to (1) smooth (balanced) work flow across a wide variety of products, (2) elimination of waste, (3) high quality output, (4) flexible operation, and (5) low total unit production costs. Economic benefits attributable to lean manufacturing include reduced lead-time and higher throughput, smaller floor space requirements, and lower work-in-process [2].

In factories using lean manufacturing, large machines characteristic of batch-and-queue processes (typically referred to as "monuments") are often no longer aligned with lean work cells and are not needed or desired. Instead, smaller more flexible machines are typically organized into work cells devoted to the production of a family of products [1,4–6]. Workers then operate the machines in the cell to minimize the cycle time for a family of products, minimize inventory, and maximize quality.

In existing factories, eliminating monuments and investing in new, smaller machines can be troublesome to managers who were responsible for originally approving a high-volume batch-and-queue manufacturing process. Scrapping a massive piece of equipment, which still has a sizeable book value, can be viewed as admitting that a mistake was made years ago by investing in manufacturing technology that quickly became obsolete. Therefore, the decision to abandon (or replace) high-volume monolithic machines in favor of cellular manufacturing systems that employ TPS and lean manufacturing principles can be extremely difficult

PII: S0736-5845(02)00016-9

for managers to make, fraught with subjective factors beyond economics.

The purpose of this paper is twofold: (1) to provide a roadmap to illustrate how value stream mapping (VSM) and its associated tools can be used to design a desired future state aligned with lean manufacturing principles and (2) to examine the economic aspects of replacement decisions created by lean manufacturing systems using information on anticipated cost savings from VSM. We begin with a discussion of VSM and its associated tools, how they are used to map a current state and design a future state. We then use a hypothetical example to quantify the typical economic benefits associated with lean manufacturing. Lastly, we analyze the economic trade-offs arising from a decision to invest in a future state including work cells that replace a high-volume transfer line.

2. Lean manufacturing

Lean manufacturing has been increasingly adopted as a potential solution for many organizations, particularly within the automotive [3,7,8] and aerospace [9–11] manufacturing industries. Although a number of principles and tools appear to be derived from Just-in-Time, cellular manufacturing, and World Class Manufacturing, lean manufacturing has emerged relatively recently as an approach that integrates different tools to focus on the elimination of waste and produce products that meet customer expectations [4,12].

Womack and Jones [4] used the term lean thinking to label the *thinking process* of Taiichi Ono and the set of methods describing the Toyota Production System. James-Moore and Gibbons [13] define key areas of focus, each with associated principles, within the lean manufacturing approach: flexibility, waste elimination, optimization, process control, and people utilization. These areas of focus and principles can be operationalized using specific tools and techniques. A number of authors have defined the portfolio of tools/techniques to implement lean manufacturing [12,14,15]. In this paper, we demonstrate how (VSM) can be used as a means to identify where waste occurs within the transfer line [4,16].

A value stream is defined as all the value-added and non-value-added actions required to bring a specific product, service, or combination of products and services, to a customer, including those in the overall supply chain as well as those in internal operations [4,17]. VSM is an enterprise improvement technique to visualize an entire production process, representing information and material flow, to improve the production process by identifying waste and its sources [17]. A VSM, both current and future state, is created using a pre-defined set of icons (shown in Fig. 1). VSM creates a common language about a production process, enabling more purposeful decisions to improve the value stream.

A value stream map provides a blueprint for implementing lean manufacturing concepts by illustrating how the flow of information and materials should operate [17]. VSM is divided into two components: big picture mapping and detailed mapping [12]. Before starting detailed mapping of any core process, it is useful to develop an overview of the key features of that entire process. The overview will help accomplish the following [12]:

- Visualize the flows.
- Identify where waste occurs.
- Integrate the lean manufacturing principles.
- Decide who should be on implementation teams.
- Show relationships between information and physical flows.

Visualizing the flow creates the ability to see where, when, and how both the information and product flows through the organization. As defined in [12], there are seven wastes that can occur in a system.

1. Overproduction—Producing too much or too soon, resulting in poor flow of information or goods and excess inventory.
2. Defects—Frequent errors in paperwork or material/product quality problems resulting in scrap and/or rework, as well as poor delivery performance.
3. Unnecessary inventory—Excessive storage and delay of information or products, resulting in excess inventory and costs, leading to poor customer service.
4. Inappropriate processing—Going about work processes using the wrong set of tools, procedures or systems, often when a simpler approach may be more effective.
5. Excessive transportation—Excessive movement of people, information or goods, resulting in wasted time and cost.
6. Waiting—Long periods of inactivity for people, information or goods, resulting in poor flow and long lead-times.
7. Unnecessary motion—Poor workplace organization, resulting in poor ergonomics, e.g., excessive bending or stretching and frequently lost items.

To describe and create an overview of a production process, “big picture” mapping is used [12,18]. Fig. 2 is a generic example of a big picture map for current state situation in a hypothetical transfer line. Fig. 2 encapsulates the five basic phases in the big picture mapping exercise [12]:

- Define customer requirements.
- Map information flows.