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A Decomposition Approach for Manufacturing System Design

David S. Cochran, Jorge F. Arinez, James W. Duda, and **Joachim Linck,** Production System Design Laboratory, Dept. of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Abstract

Successful manufacturing system designs must be capable of satisfying the strategic objectives of a company. There exist numerous tools to design manufacturing systems. Most frameworks, however, do not separate objectives from means. As a result, it is difficult to understand the interactions among different design objectives and solutions and to communicate these interactions. The research described in this paper develops an approach to help manufacturing system designers: (1) clearly separate objectives from the means of achievement, (2) relate low-level activities and decisions to high-level goals and requirements, (3) understand the interrelationships among the different elements of a system design, and (4) effectively communicate this information across a manufacturing organization. This research does so by describing a manufacturing system design decomposition (MSDD). The MSDD enables a firm to simultaneously achieve cost, quality, delivery responsiveness to the customer, and flexibility objectives. The application section illustrates how the MSDD can be applied in conjunction with existing procedural manufacturing engineering.

Keywords: *Manufacturing System Design, Manufacturing Strategy, Axiomatic Design*

Introduction

Designing a manufacturing system to achieve a set of strategic objectives involves making a series of complex decisions over time (Hayes and Wheelwright 1979). Making these decisions in a way that supports a firm's high-level objectives requires an understanding of how detailed design issues affect the interactions among various components of a manufacturing system. This paper presents an axiomatic design-based decomposition of a general set of functional requirements and design parameters for a manufacturing system and explains how this decomposition can be used as an approach to aid engineers and managers in the design and operation of manufacturing systems.

In practice, designing the details of manufacturing systems (equipment design and specification, layout, manual and automatic work content, material and information flow, etc.) in a way that is supportive of a firm's business strategy has proven to be a difficult challenge. Because manufacturing systems are complex entities involving many interacting elements, it can be difficult to understand the impact of detailed, low-level deficiencies and change the performance of a manufacturing system as a whole.

Shingo (1988) discusses the problem of optimizing individual operations as opposed to the overall process (referred to as the manufacturing system herein). Hopp and Spearman (1996) describe the same problem, calling it a reductionist approach where the focus is on breaking a complex system into its more simple components and then analyzing each component separately. They go on to point out that "too much emphasis on individual components can lead to a loss of perspective for the overall system," and that a more holistic approach can lead to better overall system performance.

The framework presented in this paper develops a tool to help manufacturing system designers (1) clearly separate objectives from the means of achieving them, (2) relate low-level activities and decisions to high-level goals and requirements, (3) understand the interrelationships among the different elements of a system design, and (4) effectively communicate this information across the organization. The structure of the framework is based on axiomatic design.

The decomposition framework for manufacturing system design and control integrates several different disciplines, such as plant layout design and operation, human work organization, ergonomics, equipment design, material supply, use of information technology, and performance measurement. The target industries of the framework are medium to high-volume repetitive manufacturing companies.

Manufacturing System Design

A manufacturing system can be defined as the arrangement and operation of machines, tools, material, people, and information to produce a value-added physical, informational, or service product whose success and cost is characterized by measurable parameters (adapted from Chryssolouris 1992, Wu 1992, Cochran 1994). To integrate the many elements of a manufacturing system into a smoothly functioning whole is the challenge addressed by the manufacturing system design process. The word "design" is a very general term that is liberally used by many people both inside and outside of engineering. While the field of product design is still growing and is extremely dynamic, practitioners have a good understanding of what it means to design a product, although the methods and approaches are still debated. Some products can be very complex, but products typically have well-defined boundaries with clearly visible attributes that lead to performance characteristics that are readily discernible by the final user/customer. Manufacturing system design, on the other hand, elicits many different definitions and interpretations of the activities involved. Part of the reason for this difficulty is that manufacturing system design is multidisciplinary and often involves many nonengineering fields. Another reason is that the notion of a manufacturing system is difficult to see, let alone visualize, in its entirety. Manufacturing system designs consist not only of physical hardware, but also of the people who manage and operate this hardware and who must communicate information within the manufacturing system as well as throughout the company's supply chain. One result of this broad scope is that it is very difficult to understand the interactions among the many details of a manufacturing system design.

In some cases, the focus of implementation is on simplified solutions and specific improvement tools (for example, implementing kanban). This approach has often been the case in companies attempting to duplicate the success that Toyota has achieved with its production system (Spear and Bowen 1999, Zipkin 1991). Hayes and Pisano (1993) note that companies trying to improve their competitiveness by implementing a program such as Just-in-Time (JIT) or Total Quality Management (TQM) seldom achieve the desired results, as they focus on these generic approaches rather than on developing their own unique competitive strategy. Shingo (1989) describes other cases where improvement activities such as installing a kanban system fail because the necessary enabling practices, such as setup time reduction and defect prevention, have not been implemented.

In this paper, manufacturing system design is defined as follows: manufacturing system design covers all aspects of creating and operating a manufacturing system. Creating the system includes equipment selection, physically arranging the equipment, work design (manual and automatic), standardization, design of material and information flow, and so on. Operation includes all aspects that are necessary to run the created factory.

Research Objectives

For a manufacturing system to satisfy the strategic objectives of a company requires that it be designed according to the following precepts:

1. Clearly separate objectives from the means of achievement

The clear separation of objectives and means allows designers to relate system details to the manufacturing system objectives. For example, manufacturing cells provide a means to satisfy numerous system objectives. However, implementing manufacturing cells without relating the use to system objectives may not lead to the desired outcome. The approach presented here allows the freedom to select among different physical implementation alternatives. The key point is to define and then achieve the desired set of objectives, regardless of the physical implementation.

2. Relate low-level activities and decisions to high-level goals and requirements

The system designers must be able to relate low-level decisions to the high-level system objectives. For example, equipment can greatly influence the way the manufacturing system is designed and operated (Arinez and Cochran 2000). Thus, it is necessary that the designers understand how the lower-level tactical design solutions achieve higher-level system design goals.

3. Understand the interrelationships among the different elements of a system design

Lower-level decisions not only affect the achievement of higher-level goals, but the decisions also interrelate with other lower-level decisions. For