Journal of Industrial Information Integration 2 (2016) 65–74

Contents lists available at ScienceDirect

Journal of Industrial Information Integration

journal homepage: www.elsevier.com/locate/jii

Incorporating design improvement with effective evaluation using the Manufacturing System Design Decomposition (MSDD)

David S. Cochran[a,*], Mohammad Umair Jafri[a], Alex K. Chu[a], Zhuming Bi[b]

[a] Center of Excellence in Systems Engineering – IPFW, Fort Wayne, IN 46805, United States
[b] Department of Civil and Mechanical Engineering – IPFW, Fort Wayne, IN 46805, United States

ARTICLE INFO

Article history:
Received 15 March 2016
Revised 18 April 2016
Accepted 22 April 2016
Available online 26 May 2016

Keywords:
Data analytics
Axiomatic Design
Manufacturing System Design Decomposition
System metrics
Continuous improvement
Knowledge integration
Information integration

ABSTRACT

The definition of system metrics is crucial to determine if a manufacturing system design is truly effective because inappropriate metrics can lead to ineffective or improperly-focused system improvements. This research highlights the importance of measuring the system design that contributes to system effectiveness. The authors propose the use of a Manufacturing System Design Evaluation Tool to assess the effectiveness of the design of manufacturing systems as a whole. The tool was developed based on the Manufacturing System Design Decomposition. The Manufacturing System Design Evaluation Tool measures how well a system is designed based on the requirements outlined in the Manufacturing System Design Decomposition. System effectiveness is evaluated based on six physical manufacturing system configurations: the Departmental or Job Shop Layout, Departments Arranged by Product Flow (sometimes called a Flow Shop), Assembly or Transfer Line, Pseudo-Cell (a cell that is called a cell but does not meet all of the requirements of a cell), individual Assembly or Machining Cells (but not yet integrated as a system), and a Linked-Cell Manufacturing System for all aspects of a production value stream. The Linked-Cell Manufacturing System is considered to be the physical configuration that represents the highest level of manufacturing system design requirements achievement. In addition, the siginificance of implementing one physical element relative to achieving the requirements of the overall manufacturing system design may be evaluated. With this feedback, management is able to identify elements of the system design that need improvement and additional resources. The proposed Manufacturing System Design Evaluation Tool may be applied to evaluate most repetitive, discrete-part manufacturing systems.

1. Introduction

Due to the twenty-first century economic globalization and the saturation of manufacturing capacity, enterprises are facing immense challenges in sustaining their competitiveness in the current business environment [1,14,26,36,37]. Manufacturing companies must ensure that improvements are effectively directed and appropriately measured through metrics programs employed [20]. The management of an enterprise needs to understand how well their enterprise is performing and whether improvement initiatives are delivering a meaningful results and return on investment (ROI) [28]. The competitiveness of a manufacturing enterprise may be evaluated by many different system metrics, such as: productivity, cost, lead time, quality, adaptability, agility, and sustainability.

Numerous researchers have worked on evaluation methodologies based on these and other metrics [2]. For example, Muthiah and Huang [22] gave a literature review on the evaluation of productivity and the methodologies of using measures for system improvement. Ray et al. [24] introduced a method to evaluate the *leanness* of production systems. Huang et al. [16] developed a process using the collected data from radio frequency identification (RFID) to measure the operational level of an Enterprise Resource Planning system. Wan [35] utilized a Data Envelopment Analysis (DEA) technique to measure the *leanness* of a manufacturing system quantitatively; where each production process was defined as a decision-making unit associated with cost, time and value. ReichWeiser et al. [25] developed a top-down approach to assess the sustainability of a manufacturing system; the system-level goals were connected to geographic and manufacturing considerations with the focus on environmental cost and sustainability. Larreina et al. [19] developed a manufacturing execution system which was capable of incorporating data acquisition, analysis and optimization to enhance sustainability goals. Bi and Cochran [5] gave a comprehensive survey on big data analytics applications for planning and scheduling of manufacturing systems. Bi et al. [4] and Bi and Wang [3] established the relationship of modularization with

* Corresponding author.
E-mail addresses: cochrand@ipfw.edu (D.S. Cochran), umaim01@ipfw.edu (M.U. Jafri), zbi@ipfw.edu (Z. Bi).

http://dx.doi.org/10.1016/j.jii.2016.04.005

adaptability in manufacturing systems. Kumar [18] discussed the impact of mass customization on five dimensions including price, quality, flexibility, delivery and service. However, the majority of these evaluation tools treat a manufacturing system as a black or grey box. As a consequence, the evaluation results based on these metrics give little direct information about how the system design should be designed and evolve over time to improve overall system performance.

When a system is as complex as a manufacturing facility, it is often very difficult to assess its design and operational performance. Most companies measure performance with traditional management cost accounting systems [17]. The financial information that is presented gives an outdated picture of operational health [34]. More importantly, financial information does not point out system design weaknesses and opportunities for improvement. This paper presents the Manufacturing System Design (MSD) Evaluation Tool, a method to measure how well a manufacturing system is designed to meet the overall system design objectives or how well that system design is implemented. By using the MSD Evaluation Tool, improvements may be directed in areas that are deficient so that resources may be allocated to make the necessary improvements and changes in design. This analysis tool is based on the use of the Axiomatic Design [29,30] methodology and builds upon the requirements of a manufacturing system design as defined by the Manufacturing System Design Decomposition (MSDD) [9,10,31]. The MSDD decomposes a general manufacturing system so that the physical tools of implementation that are part of the Toyota Production System (TPS) [21] and were characterized as *lean* [38] are connected to the engineering science / factory physics of manufacturing [15]. The MSDD defines the requirements of what a manufacturing system must achieve and then defines the tools that are sometimes associated with TPS and lean that are used commonly. The rationale for the development of the MSDD is to provide an open framework for system design innovation. To innovate, system designers and leaders must be able to understand the requirements that a system must achieve that led to the development of many of the best practices of lean and TPS implementation. The MSDD articulates lean and TPS as a system design and provides the requirements so that further innovation in physical solutions may take place. The MSD Evaluation Tool provides a reference to aid in the design of current and innovation in future manufacturing systems relative to the MSDD requirements.

2. Motivation

2.1. Defining a "good" design

An important distinction that is made in this paper attempts is to evaluate the design of a manufacturing system that creates performance results instead of using measures (financial or operational) to evaluate performance. This approach builds on Deming [13] that issues in manufacturing are a result of the system design and not the people who work in a system. Deming's concept may then be extended to the management and design of systems with the understanding that excess cost is the result of the system design and that the best way to control cost is to improve the system design. The system design includes the thinking that creates a system design that is articulated by the MSDD, the physical structure and configuration of the system and the way that work is done (called standard work) by Toyota [12]. This proposition can be difficult to make because often, systems are evaluated based on cost performance alone. In addition, traditional performance measures such as commercial value, cost, quality, innovation and customer satisfaction are also measures that are tied to implementation success. In manufacturing, many factors may contribute to the success or failure of a venture, including many issues outside the realm of manufacturing such as product design, marketing and distribution. Therefore, assessing a manufacturing system based on traditional management accounting and traditional operation performance measures [11] alone does not necessarily indicate the level of success in a particular system implementation, nor does that assessment identify opportunities for improvement in the current manufacturing system design. In order to address these issues, the goal is to evaluate the design, not the performance, which is the output and result of the manufacturing system design and implementation.

In the theory of Axiomatic Design, an optimal design is characterized by independently satisfying the functional requirements with design parameters having the minimum information content [29,30]. In design concept selection, the Pugh concept selection methodology uses a concept selection matrix that is formed with the potential design concepts and weighted selection criteria [23]. Secondly, each concept receives a score for each design criterion multiplied by its weight, and the scores for all the criteria are then summed for each physical concept that is being evaluated. The concepts are then rank-ordered based on their scores. This method is used to aid in the selection or screening of design concepts [33]. In the two approaches mentioned above, the design parameters or concepts (i.e., the physical solutions) are assessed by how each solution impacts the achievement of many functional requirements or design selection criteria specified. This type of approach will be followed in this paper, within the context of Axiomatic Design to specify design parameters that achieve functional requirements with limited or no interaction. The design parameters specify the details of implementation; while functional requirements define design intention regarding what the system must achieve to meet the needs of the customer(s).

2.2. Impact of evaluation methods on system evolution

The theme of this paper is that traditional management cost accounting drives the evolution of manufacturing systems [8]. The consequence of this evolution is not a design that meets customer needs. Instead, the result is sub-optimization of component elements of the manufacturing system. The focus of traditional management cost accounting is to reduce the cost of a single operation, rather than overall system cost. This approach leads to cost sub-optimization and design decisions at the local level (machine or grouping of machines in a department) instead of the system level (i.e., linked-cell manufacturing system) [12]. The classic example focuses on machine utilization and focuses primarily on direct labor cost reduction. In order to ensure that machines are fully utilized, workers monitor the machines (one person, one machine) to keep the uptime maximized. In addition, in order to decrease the direct labor cost under the one person, one machine design, the number of machines is reduced, resulting in the design of extremely fast, complex machines grouped into functional departments. Throughput time, inventory, and quality traceability are all sacrificed in this system design that evolves from this performance measurement approach that focuses on direct labor cost reduction. The Toyota Production System addresses these problems by arranging machines in cells according to product flow. The cells are designed so that an operator may run several machines, as long as the manual cycle time is less than or equal to the system takt time which is the average pace (time/unit) of customer demand for the system. The requirement of this system design is to ensure effective use of peoples' abilities. The approach stems from Toyota's tone of "respect for the worker" and the implementation of the system design requirement of automation with a human touch called *autonomation* [21]. In this design, machine utilization may be lower, but the machine designs are simplified to achieve