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DISCUSSION　PAPER　SERIES

No. 2014-CEGS-04

An Insight into the Role of Manufacturing Engineering in the Design and Evaluation of Reconfigurable Manufacturing Systems(RMS)

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2015 年 3 月

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Discussion paper

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1. Introduction

In the last three decades a growing body of knowledge about product development and manufacturing in the automotive industry has emerged. One of the major contributions in this field has been done by Clark and Fujimoto (1991) whose work represents a lengthy and detailed study of product development in the world automotive industry. In their book they describe the different approaches to product development that can be found in different manufacturing companies around the world. Having done so, Clark and Fujimoto (1991) provide a convincing explanation of how and why the Japanese automakers have became performance leaders in the automotive industry and also give useful advice to those manufacturers who need to radically improve their competitiveness. This competitiveness continues today in some forms (Fujimoto and Nobeoka, 2006; Thomke, 2006; Higashi and Heller, 2012).

Interest in automotive manufacturing has generated a significant number of works as well but probably the most influential among these works is Womack et al. (1990). Published at a time when Toyota was roughly half the size of the then world leader, General Motors, this book revealed to a wide Western audience the Toyota Production System (TPS) or lean manufacturing as it is labeled in the West, created a wave of interest throughout the automotive industry and paved the way for lean manufacturing to become a benchmark for performance. However, Womack et al. (1990) and subsequent works (Monden, 1993; Womack and Jones, 1996; Liker, 2004; Hino, 2006; Spear, 2008) also make the strong argument that “lean”, and by extension TPS, is not simply for manufacturing, nor was it ever intended to be.

The major works in the field of automotive industry, like the ones mentioned above, are mainly concerned with two aspects of the transition from raw materials to products: product design[1] and manufacturing. This approach may seem reasonable from the point of view that both product design and manufacturing have a specific output: product design provides the blueprints of the products that are to be manufactured, and manufacturing provides the products based on the blueprints drawn by product design. These specific outputs (blueprints and products) naturally make the performance (quality, cost, delivery, etc.) of both product design and manufacturing easy to quantify and measure.

However, one does not need to be an expert in engineering to understand that blueprints do not turn themselves into products. There are also manufacturing systems, processes, machines, tools and equipment that need to be researched and developed before manufacturing can start. In other words, in addition to product design and manufacturing, there is another important aspect of the transition from raw materials to products which is known in the literature, as well as among practitioners, as "manufacturing engineering" which is also sometimes called "production engineering" or "process engineering". These terms sometimes denote separate activities in some companies where "production engineering" tends to refer to more upstream activities while "manufacturing engineering" tends to refer to more downstream activities. In order to be consistent with the majority of the relevant literature in English, in this study the term "manufacturing engineering" is used to cover both activities.

Product and process historically have been in the center of academic and practitioner interest, however in recent years there has been a growing number of works that examine how the productivity of existing production lines can be improved and how new production lines can be introduced more efficiently (Jonsson et al., 2004; Nakaoka et al., 2005). Both tasks, at least in Japanese companies, tend to be important responsibilities of manufacturing engineering (Shibata, 2009; Whitney et al., 2007; Koike, 2008). The transfer of manufacturing processes to overseas facilities of Japanese companies has been going on for some time, however in Japan, in recent years there appears to be an increasing focus on the transfer of manufacturing

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[1] In this paper product design refers to product engineering, *sekkei* in Japanese.

engineering processes to overseas facilities (Shibata, 2009; Heller et al., 2013).

Yet, compared with the volume of literature on product design and manufacturing, there is little research that addresses the tasks and functions of manufacturing engineering. The importance of manufacturing engineering has been pointed out by Nakaoka et. al. (2005), however, it is difficult to find detailed research on how manufacturing engineering work is performed, with a few notable exceptions that tend to focus on Japan in general, and Toyota in particular.

Understanding the importance of manufacturing engineering may be further facilitated by examining suppliers. Most of the literature discusses manufacturing engineering in OEMs while suppliers tend to be away from the focus of research or amalgamated together with OEMs. Suppliers however, do add value for end-users through the products they manufacture and deliver, and especially in Japan they are heavily involved in new product development which may affect manufacturing engineering as well.

Moreover, and what is more important, the research on manufacturing engineering that has been done so far, while examining manufacturing engineering from the perspectives of operations research and human resource management, has not clearly placed the tasks and functions of manufacturing engineering in the perspective of the two major subsets (strategy and organization) of the management studies.

Some of the literature from the 1990s and 2000s seems to examine manufacturing engineering mainly from the perspective of problem-solving techniques and mathematical methods applied in the pursuit of improved decision-making and production efficiency, as well as overseeing, redesigning and controlling production processes which is closely related to the actual work of manufacturing engineers but more in the realm of systems science and operations research. Other works examine manufacturing engineering in the light of how individuals construct organizational structures, processes and practices and how these in turn create relations between individuals. Therefore, it can be assumed that the "lenses" through which researchers have been looking at manufacturing engineering are predominantly operational or related to human resource management, with some organizational aspects present.

This paper, however, provides an insight into one of the important aspects of manufacturing engineering work, namely, the design and evaluation of reconfigurable manufacturing systems (RMS).

2. Characteristics of reconfigurable manufacturing systems

To cope with the difficulties associated with existing systems and the desire to respond rapidly to variations in market demand (mix and quantity), *Koren et al. (1996, 1999)* proposed the next generation manufacturing system called the Reconfigurable Manufacturing System (RMS). RMS was introduced as a new paradigm for a production system that effectively responds to rapid changes in the market place. It comprises the traits of existing systems, i.e. the high throughput of dedicated manufacturing systems (DMS) with the high flexibility of flexible manufacturing systems (FMS) (*Mehrabi et al. 2000*). RMS is distinguished from FMS and DMS by various factors such as capacity, functionality, cost, etc. as shown in Table 1 (*Singh at al. 2007, p 3166*).

Table 1 Comparison of DMS, FMS and RMS

	DMS	FMS	RMS
Adjustable machine structure	X	X	O
Scalability	X	O	O
Flexibility	X	O	O
Simultaneously operating tools	O	X	O
Low cost	O	X	O
High throughput	O	X	O
High machine utilization	O	X	O

A reconfigurable manufacturing system (RMS) is "one designed at the outset for rapid change in its structure, as well as its hardware and software components, in order to quickly adjust its production capacity and functionality within a part family in response to sudden market changes or intrinsic system changes" (*Koren et al. 2005, p. 2*). RMS are "regarded as systems consisting of separate blocks or centers which can be added to or removed from the system" (*Nagarur 1992, p. 801*). Koren's definition also implies that the structure of the system *as well as of its machines and controls (Koren et al. 2001)* can be rapidly changed in response to market changes (demand and products) .

According to *Mehrabi et al (2000)* and *Koren (2005)*, RMS possess the following key characteristics:

- ***Modularity*** - the compartmentalization of operational functions and requirements into quantifiable units that can be transacted between alternate production schemes to fit a given set of needs.
- ***Integrability*** - the ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that enable integration and communication.
- ***Diagnosability*** - the ability to automatically read the current state of a system and controls so as to detect and diagnose the root-cause of defects, and subsequently correct operational defects quickly.
- ***Scalability*** - the ability to easily change existing production capacity by rearranging an existing production system, and/or changing the production capacity of reconfigurable components (e.g., machines) within that system.
- ***Convertibility*** - the ability to easily transform the functionality of existing systems, machines, and controls to suit new production requirements.
- ***Customization*** - the ability to adapt the customized (non-general) flexibility of production systems and machines to meet new requirements within a family of similar products.

2. Review of methods for evaluation of FMS and RMS

The work and literature in the design, evaluation, justification and implementation of RMS and FMS has been very broad. Research methodologies have included case studies, empirical research, analytical, and simulation modeling, to help understand and address the issues of the RMS and FMS justification and evaluation by organizations.

Reconfigurable Manufacturing Systems (RMS) and Flexible Manufacturing Systems (FMS) have different goals. FMS aims at increasing the variety of parts produced. RMS aims at increasing the speed of responsiveness to markets and customers (*Mehrabi et al. 2000*). RMS is also flexible, but only to a limited extent — its flexibility is confined to only that necessary to produce a part family. This is the “customized flexibility” or the customization characteristic, which is not the general flexibility that FMS offers. The advantages of customized flexibility are faster throughput and higher production rates (*Koren at al. 1999*). Other important advantages of RMS are rapid scalability to the desired volume and convertibility, which are obtained within reasonable cost to manufacturers (*Koren 2005*). The best application of a FMS is found in production of small sets of products. With RMS, however, production volume may vary from small to large (*Goebel 2004*).

According to *Sarkis and Talluri (1999, p. 2928)*, the advantages and benefits of introducing an FMS and the reasons for the lack of adoption of these systems include:

Table 6. Advantages of FMS and reasons for the lack of adoption

Advantages	*Reasons for the lack of adoption*
added flexibility	high investment hurdle rates
higher quality	the high costs and risks of the systems
more rapid short-term and long-term cycle times	requirements for more operational and managerial expertise
and sometimes, smaller production costs due to labor and materials savings	short-term performance measures and management
	inappropriate costing approaches

The authors also point out that strategic justification models that incorporate many factors, strategic and operational, tangible and intangible, help address some of these issues.

Again *Sarkis and Talluri (1999)* propose a pair-wise comparison model, which considers both qualitative and quantitative factors, for evaluation and selection of an alternative FMS. The quantitative factors include two inputs: a) c*apital and operating costs* and b) *floor space*, and three outputs: a) *improvements in work-in-process*, b) *percentage of tardy jobs*, and c) *yield*, defined as throughput minus *scrap* and *rework*. The qualitative factors include one input, *vendor reputation*, and one output, *worker approval*. Each of these qualitative inputs and outputs are critical intangible factors, which are not usually explicitly included in evaluation models for FMS. Both these qualitative variables are measured on an ordinal scale of 1 to 5.

Chang and Tsou (1993) proposed a chance-constraints linear programming model for the economic evaluation of FMS and argued that the majority of the manufacturing companies use traditional cost accounting which divides the total manufacturing expenses into cost of goods sold, operating and non-operating expenses, and income taxes. They point out, however, that *productivity, quality* and *flexibility* "which are critical measures for considering adoption of a new FMS" (*Chang and Tsou 1993, p. 160*) are not included in traditional cost accounting. In their model they incorporate the following costs:

1) Manufacturing cost consisting of
    a) *Set-up*
    b) *Material*
    c) *Labor*
    d) *Machine*
    e) *Tool*
    f) *Space*
    g) *Software*
    h) *Prevention*
    i) *Failure*
2) Opportunity cost consisting of:
    a) *Waiting time*
    b) *Idle time*
3) And two separate cost categories:
    a) *Holding cost*
    b) *Back-order*

In a case study of a manufacturing plant in the UK which produces around 2000 similar product variants and which belongs to a US-based company and a global supplier of a broad range of modules and components to the motor vehicle industry, *Abdi and Labib (2011)* concluded that *reconfiguration time* and *reusability* of RMS for both capacity (defined as maximum production rate available) and functionality (defined as the operational degree of switching from one product to another with different process requirements) are highly crucial. Therefore, reconfiguration time and reusability "must be carefully optimised as any disruption in the performing elements cause enormous impact on the system performance, particularly on process reconfigurability" (*Abdi and Labib 2011, p. 1333*).

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