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Procedia CIRP 63 (2017) 645 – 650

www.elsevier.com/locate/procedia

The 50th CIRP Conference on Manufacturing Systems

Operation-based configuration complexity measurement for manufacturing system

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Abstract

Configuration not only determines the material flow pattern but also influences the production cost in a manufacturing system. The diversity of the products and growing demands for system flexibility increases the complexity of the configuration. In this paper, an operation-based approach is proposed to measure the configuration complexity of a manufacturing system. The configuration complexity models of the stations are built with single operation, several operations and their parallel types. Subsequently, an operation-based configuration complexity model of the overall system is used to measure the configuration complexity of a manufacturing system using the information entropy. Then, the relationship of the complexity between operations and stations is quantitatively described. An assembly line example is presented to validate the model. The results show that the proposed complexity measurement may evaluate the configuration complexity of a manufacturing system.

Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems

Keywords: Manufacturing systems; complexity; information entropy

1. Introduction

The purpose of mass customization is to design and assemble a wide variety of products by combining assembly and modular interfaces to provide customized products at close to mass production costs. However, the high variety poses several challenges for manufacturing systems including complicating the assembly process, reducing productivity, and reducing product quality [1]. Besides, manufacturing systems that reduce cost and time without decreasing quality and flexibility are increasingly complex [2]. In the design stage of a production line, there might be several configuration alternatives to consider before selecting a new configuration. The objective is to adapt to the new conditions without unduly increasing the system cost or complexity or degrading the resulting product quality. However, the dynamic manufacturing environment makes it difficult to predict the effect of a decision on system performance [3]. One possible way to address these challenges is to investigate how product categories complicate the assembly process and, in turn, affect system cost, product quality and other system performances. An effective approach is to evaluate the complexity of the manufacturing system configuration to help decision makers compare alternatives.

Complexity theory provides useful approaches for the analysis of a manufacturing system's complexity [1]. The related approaches can be classified into five categories [4] as illustrated in Figure 1. The first category is non-linear dynamics. One of the most important approaches in this category is Lyapunov exponents. Following the non-linear dynamics, bifurcation diagrams and other methods from chaotic theory have also been employed for the analysis and identification of complexity measurement. The second category is information theory including Shannon entropy and Kolmogorov entropy approaches. Kolmogorov entropy makes Shannon entropy more accurate to quantify the randomness or disorder of behaviors.

2212-8271
Peer-review under responsibility of the scientific committee of The 50th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2017.03.136

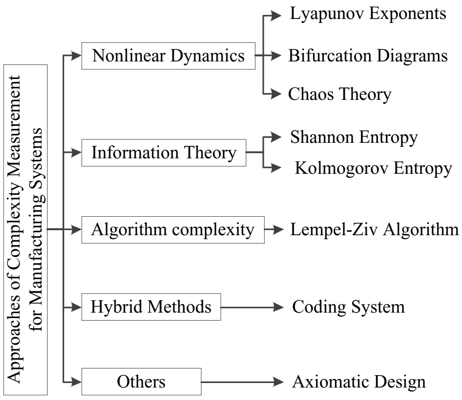

Fig. 1. Approaches of complexity measurement for manufacturing systems.

The third category is algorithm complexity. The basic premise is that a system becomes more complex with a longer number of statements that describe its behavior. The Lempel-Ziv algorithm is the most relevant algorithm. It provides a quantitative estimate of the complexity from the systems' internal structure and process. The fourth category contains hybrid methods including a coding system developed by ElMaraghy et al. [5] to classify the various types of equipment in a manufacturing system. Apart from the four categories above, other approaches like Axiomatic Design may also be relevant [6][7].

Referring to manufacturing system, researchers such as Papakostas et al. [8] modeled the complexity of manufacturing systems using nonlinear dynamics approaches. A set of manufacturing models, characterized by different production configurations and part routings, were simulated and evaluated through a series of experiments employing diverse workload patterns. Chryssolouris et al. [9] simulated a set of manufacturing models characterized by different production configurations and part routings and employing diverse workload patterns. The results are used to determine the sensitivity of a manufacturing system to workload changes.

Frizelle et al. [10] proposed a method using entropy to measure complexity in the structural and operational domains in manufacturing. Deshmukh et al. [11] enumerated factors influencing static complexity and defined a static complexity measure in terms of processing requirements of parts to be produced and machine capabilities. The measure suggested for static complexity in manufacturing systems only needs the information available from production orders and process plans. Vrabic and Butala [12] developed a metric for operational complexity that is concerned with the temporal aspects of coordination and control in manufacturing systems. The complexity is influenced by internal factors such as system structure as well as external factors such as demand.

Efthymiou et al. [13] assessed unpredictability in manufacturing via the Lempel-Ziv measure. The fluctuation of critical manufacturing performance indicators was studied to evaluate the complexity of a manufacturing system.

ElMaraghy et al. [5] developed a complexity coding system to classify and code machines, buffers, and material handling equipment that make up manufacturing systems. The code captures the amount and variety of information. The probability of a manufacturing system being successful in delivering the desired production capacity as function of the availability of its components is used as an additional measure of the system ability to meet the targeted forecast production volume with its variation as a measure of complexity. Samy and ElMaraghy [14] introduced a metric to measure the structural complexity of manufacturing systems based on the complexity inherent in the structure of its components: machines, buffers, and material handling systems. The model uses the manufacturing systems classification code developed by ElMaraghy et al. [5] to assess the contribution of each module to the overall system structural complexity even if the complexity metric is not related to the information theory approach.

Lee et al. [6] investigated the complexity concept defined in axiomatic design theory to avoid vague use of the term 'complexity' in engineering system design, to provide deeper insight into possible causes of complexity, as well as to develop a systematic approach to complexity reduction.

Other research provides a clue to develop an effective measurement for complexity, but several issues on the special features of complexity measurements must be noticed. The relationship between uncertainty of the operation and overall line configuration is rarely considered in existing complexity-measurement researches. Moreover it is difficult to measure the nonlinear relationship among each station.

Researchers generally think that information entropy theory effectively describes complexity, and the complexity features are closely related to operations, system layout, workflow, and work time. Thus, it is necessary to build a model that considers the relationship between operations and configuration to detail the inherent meaning of complexity in manufacturing systems.

Uneven loads, station blocks and rhythm disorders caused by uncertain factors increase the complexity of manufacturing systems. Complexity theory is an effective method to measure diversity and uncertainty and is used to measure the uncertainty of production system in manufacturing system. The traditional complexity measurement method emphasizes the differences in equipment types in manufacturing systems and divides the equipment into production equipment, buffer, and material handling system. The complexity of the manufacturing system is increased, and the difficulty of measurement arises. Parallel stations and sub-lines definitely influence the complexity of the overall line; it is necessary to also measure their complexity from the point of view of overall line.

In the following sections, we present an approach based on operations to measure and quantify simultaneously the configuration complexity of manufacturing system that contain parallel stations and sub-lines. A detailed description of our approach is introduced. Next, we apply it to an assembly line case study. The purpose is to develop the methodology for describing the complexity of relationship between the manufacturing processes with the system configuration, which can be applied to optimize the design of a manufacturing system configuration itself.