Chapter 17
Self-Organizing Manufacturing Systems in Industry 4.0:
Aspect of Simulation Modelling

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ABSTRACT

This chapter presents the evolution of simulation modelling methodology in the context of the Industry 4.0 paradigm and the development of autonomous, self-organizing manufacturing systems. Such a system is managed by a decision-making system that uses a detailed model of the factory, known as the "digital twin" to monitor and control the manufacturing process and test possible process reorganization scenarios. To allow self-organization within the physical world, the "digital twin" model must itself be self-organizing. That means that the structure of the simulation model can be constructed from process data, which is a novel concept, called data-driven modelling. As self-organization leads to the reorganization of existing elements and their relationships within a system, we can treat such manufacturing systems as autopoietic. The chapter introduces the Industry 4.0 paradigm and its background and presents the main self-organizing manufacturing concepts, and the state of technology supporting these concepts.

INTRODUCTION

While the 3rd industrial revolution, which started in the 1970s has brought the automation of work, the 4th industrial revolution and its Industry 4.0 paradigm bring digital transformation, or digitisation (not digitalisation) – digital enablement of all business processes, leading to quantum leaps in efficiency, productivity and innovation. With the process of manufacturing scheduling today being largely automated, the next goal in the Industry 4.0 paradigm is a dynamic, automated adaptation of manufacturing processes which leads to self-organized manufacturing systems. The availability of machines and other manufacturing resources, data from quality management systems, energy costs, availability of materials, warehousing, transport services etc. must be considered in order to dynamically optimise the

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manufacturing process. Simulation modelling tools, namely the Digital Twin concept can be used not only to monitor and control the real-life manufacturing system, but also to predict its behaviour and test optimisation scenarios. Due to the complexity of a modern manufacturing system, artificial intelligence (AI) tools are being developed to increase the (information) system autonomy in making decisions. The main goal is not to reduce workforce costs, but to ensure a quick-reacting, consistent and highly optimized management of the manufacturing system.

A modern manufacturing system, i.e. a single factory, can contain several hundred machines, which can be reprogrammed to perform various types of material processing. By changing the sequence of machines used and their programming, a very large assortment of products can be manufactured. Such a flexible factory may not represent an ontic open system, however due to the interaction of flexible manufacturing system components (i.e. machines, operators, transport routes) leading to potential new emergent states means we should nevertheless approach it as a complex system (Simon, 2010), (Curry and Dagli, 2017), and widen our systems thinking toolbox (Arnold and Wade, 2015) with methodologies that innately support autonomous system components such as agent based modelling (Gilbert, 2007), (Richiardi, 2014), (Škraba *et al.*, 2007), (Monostori, Váncza and Kumara, 2006). Bio-inspired methodologies such as genetic algorithms (Macy and Willer, 2002; Kofjač and Kljajic, 2008) are often used in manufacturing system optimization problems, demonstrating the potential benefits of building technical systems using concepts originating in biology.

The objective of this chapter is to examine the applicability of another concept originating from biology – autopoiesis, present the related concept of self-organizing manufacturing from the aspect of simulation modelling and review the state of technology supporting these two concepts. We further propose a new simulation modelling paradigm based on the concept of self-organisation. Research methodology is based on literature review of research on socio-technical systems, autopoiesis, and simulation modelling projects incorporating elements of self-organization such as automated modelling, including authors own work (Kanduc and Rodic, 2016).

The chapter presents the evolution of modelling simulation methodology within the context of Industry 4.0 paradigm, which is enabling the development of self-organizing manufacturing systems. The rationale of the autonomous manufacturing systems in the Industry 4.0 paradigm is the reduction of the need for costly and slow human intervention in manufacturing processes, to be achieved through self-organization. As in the seminal demonstration of a minimal case satisfying the conditions for autopoietic organization (Varela, Maturana and Uribe, 1974), autonomous manufacturing systems use simulation models to validate self-organization concepts, i.e. to generate and verify possible decision alternatives in the process of self-organization. As the act of self-organisation leads to the reorganisation of existing elements and their relationships within a system, we can ask the question: “Can we treat the self-organising manufacturing system as autopoietic?”

First, we introduce the motivation behind the development of autonomous manufacturing systems and examine the concept of autopoiesis in the context of socio-technical and technical systems. The Industry 4.0 paradigm is then presented in more detail, including the historical developments behind the 4th industrial revolution and Industry 4.0. Current state of Industry 4.0 is presented, and the concept of self-organizing technological systems is introduced with an overview of recent research in this field. The chapters main area of interest is the process and system management technology, and its main enabling components: system model, known as the “digital twin”, used by the decision-making system, which incorporates AI aspects in order to reduce the need for human intervention and thus allowing a degree of self-organisation. We make the case for the new simulation modelling paradigm of automated model

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