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Complex networks in advanced manufacturing systems

Yongfeng Li[a,b], Fei Tao[a,*], Ying Cheng[a], Xianzhi Zhang[c], A.Y.C. Nee[d]

[a] School of Automation Science and Electrical Engineering, Beihang University, Beijing 100191, China
[b] School of Mathematics and information Engineering, Taizhou University, Zhejiang, Linhai 317000, China
[c] School of Mechanical and Automotive Engineering, Kingston University London, London, UK
[d] Department of Mechanical Engineering, National University of Singapore, Singapore

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ABSTRACT

In recent years, with the rapid development of manufacturing, information, and management technology, advanced manufacturing systems (AMSs) have become increasingly more and more complex, which hinders the wider applications of many key theories and technologies in AMSs. Fortunately, in the last two decades, some dramatic advances have been made in the field of statistical physics theories, along with the extensive applications of complex network. It has provided an alternative approach to analyze AMSs. Many recent studies have focused on the theory of complex networks to describe and solve complicated manufacturing problems. Based on a great number of relevant publications, this paper presents an up-to-date literature review with the identified outstanding research issues, future trends and directions. Three critical issues are summarized after this investigation: (a) the focused areas of AMSs that have deployed the theory of complex networks, (b) the addressed issues and the corresponding approaches, and (c) the limitations and directions of the existing works.

1. Introduction

The scientific development in the past few years indicates that the social environment for manufacturing has changed significantly, such as the growing global market competition and the diversity of customer demands. Responding to the changing environment, the manufacturing industry and related enterprises have been paying more attention to some manufacturing characteristics such as agile, networking, service-oriented, green, socialization, etc [1–3]. In order to reach the goals of TQCSEFK (i.e., fastest Time-to-market, highest Quality, lowest Cost, best Service, cleanest Environment, greatest Flexibility, and highest Knowledge), researchers have proposed a variety of advanced manufacturing systems (AMSs) and modes [4].

AMSs have been playing a vital role during the last 20 years in the manufacturing industry development. However, focusing on the modes, architectures, key technologies, and application platforms of different AMSs, the literatures still seem to be lack of statistical researches, especially in the field of the broader applications in manufacturing industry. Fortunately, in the last two decades, researchers have witnessed dramatic advances in the statistical physics theories of complex networks [5–7], which has provided an alternative approach to analyze the AMSs. The origin of complex network is discrete mathematics and graph. It provides a set of tools to quantitatively analyze the structural heterogeneity of networks. It has developed over decades as a theoretical framework for the understanding of the network structural characteristics. Inspired by real-world networks, a great number of interdisciplinary studies of complex networks have led to the development of many empirical network metrics. Its models apply across a wide range of research fields successfully.

Based on the search of Web of Science, Scopus, Springer Link, IEEE Xplore, Journal of Mechanical Engineering and Journal of Computer Integrated Manufacturing Systems (two journals which are the most authoritative academic journals in the field of digital and advanced manufacturing in China), 150 articles on complex networks in AMSs from 2000 to 2015 are collected and selected in this paper. The paper reviews and analyzes the literatures systematically with the aim to investigate the applications of complex networks in AMSs and then provides some references for the in-depth studies on AMSs.

The rest of this paper is organized as follows. Section 2 describes the research methodology and classifies the literatures on complex networks in AMSs. Section 3 gives the detailed reviews and discussions of the selected researches. Based on the identified limitations, the future trends and derived further works are pointed

* Corresponding author.
E-mail address: ftao@buaa.edu.cn (F. Tao).

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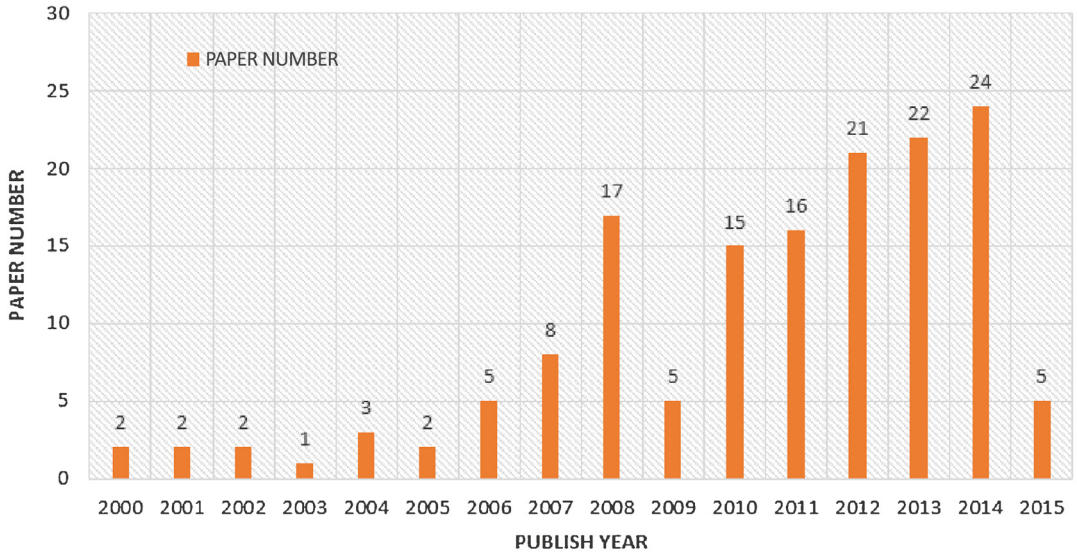

Fig. 1. Paper distribution in international journals and conferences since 2000 (up to April 1, 2015).

out in Section 4. Finally, Section 5 summarizes the whole paper and the contributions.

2. Complex networks in AMSs

In order to review the literatures systematically and clarify the research methodologies, from (1) material collection, to (2) category selection, and (3) descriptive analysis, three steps are described for the researches on complex networks in AMSs.

2.1. Material collection

Material collection methodology is the first step of the literature review process. The review is based on the search among academic journals, articles and books, primarily in Scopus, Web of Science (WoS), Springer Link, IEEE Xplore, and the most authoritative two related journals in China (i.e., Journal of Mechanical Engineering, and Computer Integrated Manufacturing), ranging over the period from 2000 to 2015 (up to April 1, 2015). The review primarily focuses on the applications of complex networks in AMSs. Besides, it is carried out in three stages: (a) searching in scientific databases with relevant keywords, (b) identification of relevant papers from reading abstracts; and (c) full-text reading and grouping into specific research topics.

The main relevant manufacturing fields are manufacturing systems networks, manufacturing networks, collaborative manufacturing networks, collaborative product design networks, product networks, production/manufacturing process networks, supply chain networks, logistics networks, sensor networks, resource services networks, etc. Finally, 150 articles in total were selected, reviewed and examined in detail. The number of articles analyzed for the review appears to be adequate as the focus on specific issues, which is consistent with the number of articles analyzed in recent literature reviews in the area of manufacturing.

2.2. Category selection

The selected articles were sorted out from more than fifty journals. The corresponding annual distributions of the selected articles are shown in Fig. 1. Obviously, most of the selected articles were published in recent five years.

Regarding to the selected articles, there are various types of study subjects about complex networks in AMSs. Furthermore, considering the whole lifecycle of product, and pursuing the full cooperation and integration of labor, process and resources in a single enterprise or among multiple ones, a framework model of manufacturing system network is constructed based on introducing Internet into manufacturing [8]. As shown in Fig. 2, the framework model is classified into two categories: *in enterprise* and *among enterprises*.

1) *In enterprise*:It promotes the integration of production-related information, product-related information, and other business management information, and the integration of the workshop and other enterprise information subsystems, as well as the integration of the planning and controlling information in the physical manufacturing execution process from materials and semi-finished products to the final products. Enterprises can generate manufacturing resources services for the participations in the external supply chain, in addition to the management of the internal supply chain.

2) *Among enterprises*:It addresses the information integration, storage, retrieval, analysis, use, data security, and other issues during ubiquitous services management and application processes among massive different enterprises.

According to the two classified categories above, the selected articles just pay attention to some of the specific issues illustrated in the framework model of manufacturing system networks. As shown in Fig. 3, from the two categories of 'in enterprise' and 'among enterprises', the selected articles are mainly focused on the sub-categories such as product design stage and production stage, enterprise collaboration, services, supply chain, logistic networks, and organization structure, respectively.

2.3. Descriptive analysis

For the classification of the selected articles, the distributions by categories are descriptively counted and illustrated in Fig. 4 and Table 1. As can be seen, the applications of complex networks in AMSs are mainly concentrated on the product production stage (20%), product design stage (19.4%), supply chain (16.7%), enterprise collaboration (15.3%) and service (11.3%). In addition, for the specific issues of each sub-category, supply chain, industry application and product manufacturing process are the top three research

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