Computers in Industry 80 (2016) 54–68

Contents lists available at ScienceDirect

Computers in Industry

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

Ecosystem-inspired enterprise modelling framework for collaborative and networked manufacturing systems

Amjad Fayoumi

Computing and Technology, Nottingham Trent University, Nottingham, Clifton NG11 8NS, UK

ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form 1 March 2016
Accepted 12 April 2016
Available online 6 May 2016

Keywords:
Collaborative manufacturing network (CMN)
Enterprise modelling (EM)
Enterprise simulation
Ecosystem theory
Enterprise analysis and design

ABSTRACT

Rapid changes in the open manufacturing environment are imminent due to the increase of customer demand, global competition, and digital fusion. This has exponentially increased both complexity and uncertainty in the manufacturing landscape, creating serious challenges for competitive enterprises. For enterprises to remain competitive, analysing manufacturing activities and designing systems to address emergent needs, in a timely and efficient manner, is understood to be crucial. However, existing analysis and design approaches adopt a narrow diagnostic focus on either managerial or engineering aspects and neglect to consider the holistic complex behaviour of enterprises in a collaborative manufacturing network (CMN). It has been suggested that reflecting upon ecosystem theory may bring a better understanding of how to analyse the CMN. The research presented in this paper draws on a theoretical discussion with aim to demonstrate a facilitating approach to those analysis and design tasks. This approach was later operationalised using enterprise modelling (EM) techniques in a novel, developed framework that enhanced systematic analysis, design, and business-IT alignment. It is expected that this research view is opening a new field of investigation.

1. Introduction

From the beginning of the Industrial Revolution, manufacturing has experienced a series of changes in paradigm: Quantity of production, cost reduction, quality of production, customisation, lean manufacturing, knowledge- and collaboration-oriented manufacturing, and most recently crowdsourcing and cloud-based manufacturing [1]. The manufacturing environment is usually complex, hard to predict and composed of many interdependent systems, It is also characterised by rapid change and uncertainty, which makes analysing and designing practices rather challenging. Manufacturing value and supply networks in complex socio-economic systems [2,3] typically show characteristics such as multi-scale interactions with high contingency and nonlinearity, emergent behaviour, pattern formation, and self-organisation. Clearly, the new socio-economic landscape and production techniques have led to increased efficiency, speed, and accuracy; but at the same time, they have increased the complexity of the way companies do and manage business. It is difficult to manage and control these emergent forces and technology on the one hand, and the increasing number of influencing factors on the other; even the most optimistic information and communication technology (ICT) design initiatives have been less than successful in achieving the desired manufacturing and business goals. Complex and nonlinear behaviours entail unfamiliar flows and unexpected sequences; they are mostly not visible or understandable, and are sometimes uncontrollable or uncertain. These kinds of complex behaviours cannot be envisaged by designers, or managed by operators, without extensive modelling and simulation.

In this context, many modelling and simulation approaches were adopted; some influenced by computer science approaches, and some inspired by operations research. Enterprise modelling approaches provide a holistic view of an enterprise's structural, functional, and behavioural aspects, and allow for better operational design, business-IT alignment, and performance measurement. In fact, they also offer a foundation for business and technical development and advancement—although some other approaches were adopted in similar contexts, such as soft system methodology [4], systems thinking [5], and operation simulations [6]. However, these approaches can be advanced by reworking their theoretical and practical use to better fit with the notion of collaborative and networked manufacturing ecosystems.

The research presented in this paper draws on a theoretical discussion and proposes developing a "framework" to better understand the complex and evolvable nature of the collaborative manufacturing network (CMN). The design of this framework takes

E-mail address: amjad.fayoumi@ntu.ac.uk (A. Fayoumi).

http://dx.doi.org/10.1016/j.compind.2016.04.003

into consideration the agility and effectiveness of the holistic analysis to design enterprises and their underlying information systems, and suggests practices that support modelling and simulation in the digital era. To this end, this research is founded on connecting the principles underpinning two research domains, namely those of (a) ecosystem theory, and (b) enterprise modelling, and this novel research view opens a new field of investigation. The main research questions this paper aims to answers are:

1. What lessons can we learn from ecosystem theory to better understand the collaborative manufacturing network environment?
2. How can the new understanding be reflected in a practical diagnostic enterprise modelling framework?

The paper is organised as follows: Section two briefly reviews the current approaches and state of the art in collaborative networked manufacturing analysis and design, and discusses their limitations and the challenges facing CMN enterprises. Section three describes the research methodology used in this paper, and section four discusses the utility of ecosystem theory. Section five reviews and then introduces the enterprise modelling framework in terms of its conceptual perspectives, process, and supportive tools. Finally, section six provides a set of concluding remarks, and recommends a direction for future work.

2. Challenges faced by CMN enterprises

Traditionally, manufacturing enterprises have a supply chain where suppliers provide raw materials, and distributors offer channels to market and sell products to end customers. As mentioned in the previous section, the current open market economic model is highly demanding, and presents manufacturing enterprises with new challenges. Customers are looking for better services, technology is continuously advancing, and the number of competitors is increasing. To face these challenges, manufacturing enterprises need to work more intelligently, and so they have adopted new business models that address current market conditions more effectively. Strategies such as outsourcing, offshoring, and externalising business activities – especially the secondary and support activities – have become more acceptable to every enterprise that wants to modernise its business activities and remain competitive on a global scale. Internet business models have optimised this process, allowing customers to easily buy products directly from the manufacturing company online. Supply agreements can also be easily reached over the Internet. This allows a greater variety of global business options, not only for the end customers, but also for the manufacturing enterprises themselves, transforming the supply chain into a dynamic network. What makes this network dynamic is the agility of its nodes – the ability for any of them to change their relationship and connection to the others, according to market requirements and the level of value created for the enterprise from the other side. Manufacturing enterprises began utilising information systems (ISs) in order to have better control over their activities, offer a better customer experience, and to work collaboratively – with either partners or customers – to produce innovative product designs, increase service quality, and customise and personalise manufacturing services. For example, Montreuil et al. [7] introduced the NetMan strategic framework, which considers the decentralised manufacturing activities favoured by the nature of the new open market. As a result of this work, the authors provided significant classification of granularity, responsibilities, capacities, interactions, contracts, and pattern-based design for different network configurations. Lee et al. [8] presented a number of innovative business models which go beyond the traditional supply or value chain, where a network of organisations collaborate to generate value in an open innovation model. In their global engineering network (GEN) proposal, the authors suggest five perspectives for investigation [9,10]: 1) Network structure, 2) operations processes, 3) governance systems, 4) support infrastructure, and 5) external relationships. Based on this classification, Zhang and Gregory [11] found that enterprises configure their value chain and operations based on one of three generic drivers: Efficiency, innovation, and flexibility. They go on to propose guidelines for enterprise design compatible with the GEN concept.

On the information systems side, Montreuil et al. [7] suggest that agent-based simulation is required for their developed NetMan framework in order to optimise and predict network behaviour. Wang [12] presents an IS framework to support collaborative manufacturing services which considers interesting technical capabilities such as ontology use (OWL) and semantic software services (WSDL-S). We also can find in [13] an approach to measuring the impact of implementing new "RFID" technology on cost reduction in networked manufacturing; the authors suggest that implementing RFID can improve the overall manufacturing operation and positively influence the total supply chain cost.

Although the previous studies have inspired and helped to formalise emergent thinking in the manufacturing domain, most manufacturing enterprises still optimise their activities locally rather than performing global network optimisation [14]. Also, the manufacturing enterprises in many countries fail to cope with environmental changes, which implies a failure in increasing innovation and service sustainability to a level that lives up to global market demand. This may result in increasing the risk of losing markets, or at minimum losing customer trust.

The final critical issue is related to risks taken during the decision-making process in CMN; since the CMN is highly dynamic, many decisions need to be made continuously, and changing strategic choices might bring serious risk and losses to different levels of enterprise granularity. Previous literature did not address the alignment issue among theories, practices, tools, and information systems development. Therefore, a systematic and semantic approach using intensive modelling and simulation is required to support decision-making during both enterprise design and operation.

3. Research methodology

The science of design focusses on producing and reproducing artefacts in order to fulfil some human purpose or need. Artefacts are produced, using principles of science and engineering, from either organic objects or previously produced artefacts. Human understanding and comprehension play an important role in defining what the artefacts are, for what purposes they are required, what to use in order to produce said artefacts, and how the artefacts themselves are produced. Design science has recently been widely adopted as a research approach, particularly within information systems and operations research [15,16]. This paper is based on the approach presented in [17], which offers a design science framework for theory development in information system researches (DSRIS). The data collection will rely on historical evidence that supports the argument of the paper from the ecosystem principles point of view. Data analysis techniques considered in this research are similar to those suggested in grounded theory research [18], and many of these methods (e.g. data classifying, connecting, comparing, and criticising)