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Selecting manufacturing partners in push and pull-type smart collaborative networks

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ABSTRACT

The idea of Collaborative Manufacturing, also known as the Production Networks or Social Manufacturing, has been around for more than 25 years. It is a production concept based on non-hierarchical collaboration among enterprises often referred as Virtual Enterprise (VE). Despite many scientific research and projects with this topic, it is difficult to find an example of fully operational non-hierarchical production network anywhere in the world. However, that fact could be changed very soon. Namely, the new industrial revolution, called Industry 4.0, encourages industrial enterprises to adopt information-communication technology (ICT) and Internet of Things (IoT) into their production systems, thus creating Cyber-Physical Production System (CPPS). From the aspect of production networks, CPPS represents crucial infrastructure, or a missing link between enterprises. Now, with CPPS in place, non-hierarchical networking and collaboration becomes possible through Smart Collaborative Production Networks. In this research, the concept of information system for Smart Collaborative Production Networks was developed and called 'VENTIS'. Although the idea of the concept is to manage the collaboration inside Virtual Enterprise, in this research, a special focus has been put on manufacturing planning phase in which optimization problem known as the Partner Selection Problem (PSP) occurs. Since the PSP in manufacturing phase is far more complex than partner selection during the collaborative product development phase, new research premises regarding the Virtual Enterprise type have been set. Two types of Virtual Enterprise business models – Push-type and Pull-type – have been defined in this research. If VE is Push-type, HUMANT algorithm is used to solve PSP that occurs in that case. If VE is Pull-type, a special procedure, inspired by phenomenological reduction, has been established in which set of *a priori* created VEs is compared with theoretically 'the best' VE and theoretically 'the worst' VE. Enterprises' data of production network from Dalmatia (Split-Dalmatia County, Croatia) is used as a Case Study to present 'VENTIS' concept and to present the procedure for creation of sustainable Virtual Enterprise.

1. Introduction

Geographically-dispersed networked organizations have been in focus of scientific research for more than 25 years. Different names have been used to describe this virtual type of the organization: virtual organization [1], network of enterprises [2], extended enterprise, or, simply, virtual enterprise [3]. From the very beginning, industrial production was seen as one of the main applications of the virtual organization. Therefore, new concepts – agile manufacturing [4], production networks [5], or social manufacturing [6] – were seen as a new industrial model for world leading manufacturing industries, like the one in USA [5], China [4], and EU [7,8].

On the other hand, the agile manufacturing and other new manufacturing paradigms required new type of manufacturing systems, therefore, the reconfigurable manufacturing system was presented by Koren et al. [9] in 1999. Nevertheless, at the same time, idea of realizing agility and re-configurability through production networks was also born, by Leigh Reid et al. [3] in 1996, and Wu et al. [4] in 1999. The fact is that reconfigurable manufacturing systems are based on workplaces with reconfigurable machines. However, in production network, one workplace can be presented by one enterprise which is one whole manufacturing system itself. Since manufacturing system usually have different machines, the re-configurability and adaptability of such a workplace is guaranteed. This characteristic of production network is schematically presented in Fig. 1.

However, non-hierarchical production networks consisting of autonomous enterprises didn't become fully operational in practice after more than twenty years of scientific research. In the most cases they are

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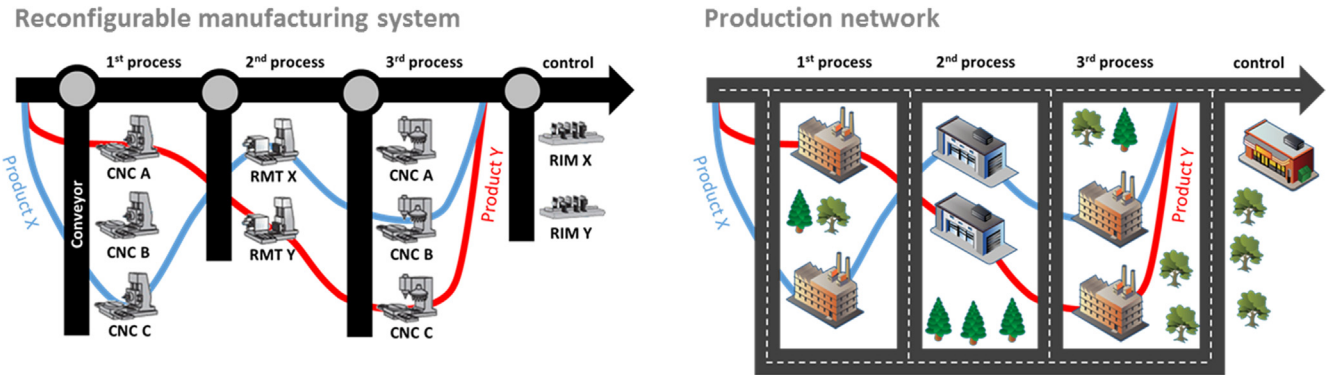

Fig. 1. Schematic phenomenological comparison of Reconfigurable Manufacturing System and Production Network.

R&D projects or living labs. Although some global corporations are using their own production networks (hierarchical model [10]) across continents [11,12], it is not at all similar concept to the original idea of non-hierarchical production networks (holarchical model [10]). The main reason why production networks did not become operational in practice, probably lies in low level of ICT integration into production systems of the enterprises. Koren et al. [9] pointed out that in order to achieve re-configurability, machines should have universal and standardized interfaces including both, hardware and software. The same thing is with enterprises, they should have standardized protocols and interfaces for information exchange, i.e. data-source interoperability [13]. But few years ago, this change begun to happen through development of new industrial platform: Industry 4.0 [14].

Since platform Industry 4.0 has its main foundations in cyber-physical interpretation of production system (i.e. in Cyber-Physical Production System – CPPS), creating a concept known as Smart Factory [15], it has built-in ability to manage networked production systems. This introduces a new type of production network concept called Cyber-Physical Production Network [16], or, similarly, Network of Socio-Cyber-Physical System [17], or, recently, Social Manufacturing [6].

Smart Factories have preposition to achieve information exchange in real-time across enterprises borders enabled by CPPS, thus allowing creation of flexible value chain with innovative product development and agile manufacturing. It is the reason why the production networks are seen as one of the most important elements of Industry 4.0. For instance, according to Roßgoderer et al. [15], three key elements of Industry 4.0 are: cyber-physical production systems, fusion of virtual and real word in product design, and production networks as flexible value chains.

In this research, a term 'Collaborative Production Networks' [18] is extended with the attribute 'Smart' and used for description of a modern production networks based on Industry 4.0 platform. The 'Smart Collaborative Production Network' should be supported by the information system, which becomes quite complex one, as it will be discussed later.

Perhaps the most challenging aspect of the VE information system is that it should incorporate elements of social network and decision-making. Each time when there is a need to create an new VE a decision needs to be made what enterprises will be part of this new VE. That decision-making problem is called the Partner Selection Problem (PSP) [4,19].

The selection of optimal partners, or solving of the Partner Selection Problem (PSP), is based on an evaluation and comparison of enterprises based on some criteria of excellence [19–21]. PSP can be solved using different metaheuristic algorithms and/or multi-criteria decision-making methods, like: AHP in combination with Ant Colony Optimization [19,22]; PROMETHEE method [23]; Particle swarm algorithm [24]; TOPSIS method [25]; DEA in combination with Genetic algorithm [26], and other different deterministic [4] or metaheuristic approaches [27–30]. Different sets of criteria are used for virtual enterprise evaluation and comparison, but the dominating criteria are: price, time, quality, and transportation cost; similarly to criteria that are commonly used in supplier evaluation [31–33]: quality, delivery time, price (price of product plus all other costs, including transportation cost). Because of transportation cost, it is important to take into account geographical dispersion of partners [34].

From a practical point of view, three smart collaborative platforms have been developed conceptually and practically to the very high technology readiness level: PlaNet [35], ManuCloud [36], and IMAGINE [37]. The platform for a production network planning – PlaNet is focused on a whole production process, not just a manufacturing. Special focus has been given to the Net Planning Assistant emphasizing automated negotiation process [35]. The ManuCloud project and platform introduced Manufacturing-as-a-Service (MaaS) concept [36]. Furthermore, IMAGINE platform represents the most comprehensive smart collaborative platform for network manufacturing. It is focused on the virtual enterprise lifecycle and partner selection [37] which is very similar to the supplier selection models. However, all of these researches have put focus on the different aspects of the management of collaborative production (or manufacturing), therefore it is difficult to compare them mutually, or to compare them with this research. Yet, they prove that this is an interesting research topic.

Aim of the research, presented in this paper, was the implementation of the multi-objective optimization algorithm – HUMANT algorithm – into the procedures and information system, also designed in this research, to support the creation of the Virtual Enterprise. The focus was on manufacturing, i.e. the selection of optimal partners (enterprises) for steps of manufacturing process. It means that collaborative product development or similar projects are not part of this research.

Before any discussion about methodology, algorithm and procedure for solving the Partner Selection Problem, two research premises regarding Virtual Enterprise type and sustainability must be set:

(1) *Virtual Enterprise must be sustainable* – there are two types of sustainability in the case of VEs: inner and outer sustainability. Outer sustainability is the VE's support to sustainable development and it is focused on a harmony among 3P's of sustainable development: People (society), Planet (environment), and Profit (economy). Practically, it means that minimization of manufacturing costs is only one criterion among set of criteria in the Partner Selection Problem. Economic criteria, like reduction of transport, and social criteria, like selecting partner from a region with high unemployment, should be considered. Although there are researches in which virtual enterprise is evaluated only through cost [4], many researchers agree that virtual enterprise cannot be evaluated only through cost [19,29,38,39] but through set of criteria, therefore, multi-criteria (multi-objective) approach becomes mandatory. On