PRODUCTION NETWORKS AND PARTNER SELECTION PROBLEM

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Abstract: *The process of globalization, and recently global economic crisis, are forcing researchers to seek for new flexible business-organizational structures. It is clear that the classical vision of the enterprise and its activities no longer corresponds to economic realities. New manufacturing paradigm called personalized production is taking place. Personalized production creates a new vision of a modern enterprise which needs to unite the somewhat contradictory requirements: specialization vs. flexibility. There is a need of new production systems, like reconfigurable manufacturing system. Systems that can achieve the ultimate goal: to be “living factory”. However, such a reconfigurable structure as “living factory” can be also achieved by networking small and medium-sized enterprises (SMEs) into production networks. It is only important that every SME of production network is capable and willing to be part of special cooperation inside network called virtual enterprise (VE). For each new product a new virtual enterprise is formed from different SMEs. Furthermore, the evaluation of enterprises performances is needed to solve the problem of the selection of enterprises in production network, or partner selection problem. Since, the partner selection problem is multicriteria problem it is necessary to use some multiple criteria decision analysis (MCDA) method. However, to completely solve partner selection problem a combination of metaheuristic optimization algorithms and MCDA methods must be used. In this chapter, usage of special multiple criteria decision analysis (MCDA) method is presented. General conclusion is that production networks represent future of manufacturing; especially they represent possible solution for the new production-organizational paradigm “Production as a Service”.*

Key words: *production networks, partner selection, personalized production, living factory*

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1. Introduction

The process of globalization, and recently global economic crisis, are forcing researchers to seek for new flexible business-organizational structures. It is clear that the classical vision of the enterprise and its activities no longer corresponds to economic realities. This fact is especially true when it comes to manufacturing enterprises.

Fig. 1. Manufacturing paradigms (Koren, 2010)

Today's manufacturing enterprises need to have a high degree of specialization in different narrow fields of work, and, at the same time, a flexible manufacturing system that will listen to and adapt to the needs of customers (a very specific ones, and a wide range ones). New manufacturing paradigm called personalized production is taking place (Figure 1).

According to Y. Koren globalization has created a new, unprecedented landscape for the manufacturing industry, one of fierce competition, short windows of market opportunity, frequent product introductions, and rapid changes in product demand (Koren, 2010). Indeed, globalization is challenging, but it presents both threats and opportunities. So the challenge is to succeed in a turbulent business environment where all competitors have similar opportunities, and where customer wants personalized product. There are two types of personalized products (Koren, 2010):

- **Product's regional fit** – Besides culture and market, regionalization must take into account additional limitations: purchasing power, climate, and legal regulations (e.g., safety, environmental limitations, and driving on the left side of the road). Market research that collects and analyzes information about the habits and needs of customers in the target country is a necessity for the product's success.
- **Product personalization** – Products that are manufactured to fit the buyer's exact needs are likely to become a new source of revenue in developed countries.

Personalized production creates a new vision of a modern enterprise which needs to unite the somewhat contradictory requirements: specialization vs. flexibility. Traditional flexible manufacturing systems are not able to fulfill those requirements and to be economical in the same time. There is a need of new production systems, like the one presented by Y. Koren: reconfigurable manufacturing system (Koren, 2010). The reconfigurable manufacturing system is much more flexible than flexible manufacturing system. According to Y. Koren there are three main principles of reconfigurable manufacturing system (RMS) (Koren et al., 2010):

1. An reconfigurable manufacturing system provides adjustable production resources to respond to unpredictable market changes and intrinsic system events:
 - RMS capacity can be rapidly scalable in small increments;
 - RMS functionality can be rapidly adapted to new products;
 - RMS built-in adjustment capabilities facilitate rapid response to unexpected equipment failures.
2. A reconfigurable manufacturing system is designed around a product family, with just enough customized flexibility to produce all members of that family.
3. The reconfigurable manufacturing system core characteristics should be embedded in the system as a whole, as well as in its components (mechanical, communications and control).

For instance, the environment of many manufacturing enterprises is characterized by unpredictable market changes. Reconfigurable manufacturing system meets these requirements by rapidly adapting capacity and functionality to new situation. Implementing RMS characteristics and principles in the system design leads to achieving the ultimate goal: “living factory” (Koren et al., 2010). The “living factory” can rapidly adjust its production capacity while maintaining high levels of quality.

However, such a reconfigurable structure as “living factory” can be also achieved by networking small and medium-sized enterprises (SMEs) into production networks. It is only important that every SME of production network is capable and willing to be part of special cooperation inside network called virtual enterprise (VE) (Camarinha-Matos et al., 2001). For each new product a new virtual enterprise is formed from different SMEs (Figure 2).

Fig. 2. Formation of virtual enterprise inside production network

According to L.M. Camarinha-Matos (Camarinha-Matos et al., 2007) virtual enterprise is a temporary alliance of enterprises that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks. Two key elements in this definition are the networking and cooperation, as most important part (Schermerhorn et al., 2002). Clearly, there is a tendency to describe a virtual enterprise as a network of cooperating enterprises. A number of pre-existing enterprises or organizations with some common goals come together, forming an interoperable network that acts as a single (temporary) organization without forming a new legal entity nor establishing a physical headquarter. In other words, virtual enterprises materialize through the integration of skills and assets from different firms into a single business entity. The idea of virtual enterprise compared to other types of virtual organization is shown on the following figure (Figure 3).

So, in production network each SME has its autonomy, because this network is non-hierarchical. Such a network contains elements of a holistic system, such as for example: ants in nature. Each ant is an autonomous, but all the ants communicate with each other and cooperate for the benefit of the entire anthill. This is the basic idea of production network. Which means, all enterprises in the network, in addition to already existing cooperation, are willing and able to develop new cooperation on new projects forming a new virtual enterprise?

Fig. 3. Types of virtual organization (Camarinha-Matos et al., 2001)

SMEs, which primarily apply new technologies with ease, were recognized by the European Union as the key factors of transformation of the European “knowledge-based economy” (KPMG Special Services, 2003). According to the EU, the enterprise is classified as SME if: it's independent, have fewer than 250 employees and balance sheet total not exceeding €43 million. In addition, SMEs can be parsed to very small (micro) enterprises having fewer than 10 employees. A further reason of EU investment in SMEs is their share in the total number of enterprises: 99.8% (Figure 4).

Fig. 4. Structure of industrial enterprises in the EU

A particular potential are micro enterprises that have the productivity level of 62% which is up to 25% less than productivity of SMEs (Müller, 2006). This lack of productivity is primarily classified as unused capacity or lack of work. When it comes to the Republic of Croatia, the structure of industrial enterprises is similar (Figure 5).

The only difference is that in the Republic of Croatia half of employees in the industrial sector are in LEs, while in the EU about a third of employees are in LEs. However, trends in the period 2004-2007 show an increase in the number of SMEs by 39.6% (Table 1) and an increase in number of employees by 22.6% (Table

2) (Mladineo et al., 2011). While in the same period the number of LEs remained the same, and number of their employees declined by 2.1%.

Fig. 5. Structure of industrial enterprises in the Republic of Croatia

	<i>Large</i>	<i>Small and medium</i>	<i>Micro (Very small)</i>
2004	210	2.108	4.133
2007	210	2.942	4.523
Increment	0,0%	39,6%	9,4%

Tab. 1. Number of industrial enterprises in the period 2004-2007 (DZS)

	<i>Large</i>	<i>Small and medium</i>	<i>Micro (Very small)</i>
2004	155.181	105.874	14.927
2007	151.867	129.819	16.862
Increment	-2,1%	22,6%	13,0%

Tab. 2. Number of employees in industrial enterprises in the period 2004-2007 (DZS)

The general conclusion is that the Republic of Croatia is catching up with EU trends in the structure of industrial enterprises, as well as in the structure of their employees. Therefore, the EU strategy for the development of SMEs should begin to apply in Croatia.

Fig. 6. Structure of industrial enterprises in Japan

I Similar structure of SMEs can be found in country with some of the world's best production systems: in Japan (Figure 6) (Mladineo et al., 2011). That clearly shows that networking of SMEs has a global potential and it represents a future of production systems.

In 2011, to stimulate research and development of SMEs production networks, European Union has funded six FP7 projects with more than 37 million € budget: ADVENTURE, BIVÉE, ComVantage, GloNet, IMAGINE, and VENIS. It appears that one of the key strategies of development of SMEs is their networking in regional production networks

2. Production Network Models

Concept of production networks is a research field of scientists all over the world. In EU: Germany (Bölt et al., 2000; Gerber et al., 2004; Neuberta et al., 2004; Roth et al., 2005; Jähn et al., 2006; Müller et al., 2006; Ackermann, 2007; Jaehne et al., 2009; Kampker et al., 2010; Ganß et al., 2011; Lau et al., 2011), Belgium (Vancza et al., 2011), Hungary (Schuh et al., 2008), Portugal (Camarinha-Matos et al., 2001; Pinto Leitão, 2004), Netherlands (Camarinha-Matos et al., 2007), Spain (Giret et al., 2009), Italy (Villa et al., 1998; Corvello et al., 2007; Manzini et al., 2011), Greece (Assimakopoulos et al., 2003) and Croatia (Mladineo et al., 2011); in USA (Leigh Reid et al., 1996; Sturgeon et al., 2002); in China (Hongzhao et al., 2005), Japan (Yamawaki, 2002) and South Korea (Choi, 2005); in Columbia (Micán et al., 2011) and Brasil (Lima et al., 2011). However, only few concepts (models) have been completely developed to be implemented in practice. These three models are: competence-cell-based network, complexity-based model, and core competence cell model.

2.1. Competence-cell-based Network

According to E. Müller et al. (Müller et al., 2006) the current mode of cooperation is mostly hierarchical. In most cases, the two components of co-operation, operation and communication, are delegated to different hierarchical levels: operation to the shop floor level and the inter-organizational communication to the management level. The "redirection" of communication regarding the co-operative production process, produces process losses and prevents direct feedback from shop floor to shop floor.

So the idea was to seek for the non-hierarchical cooperation concept of networking of small and medium-sized enterprises. Such a network is called competence-cell-based network (Müller et al., 2006). Each enterprise represents a single competence-cell, since the employees of each company have a specific set of competencies. However, each competence-cell retains its autonomy, because this network is non-hierarchical.

This concept is particularly interesting for application in Croatia, since the economy of Croatia has very similar problems with slow recovery from real-socialist production system, like ex-Eastern Germany.

2.1.1. Competence cell

A competence cell (Müller et al., 2006) is considered as smallest autonomous indivisible performance unit of value adding. The human competences of each cell are obtaining crucial importance, so the human is in the centre of the competence cell. There are different types of competence cells, covering the whole value adding process: marketing competence cells, product development competence cells, production planning competence cells, manufacturing competence cells, assembly competence cells and quality control / service competence cells. E. Müller et al. developed generic model of the competence cell (Müller et al., 2006) (Figure 7) based on general production theory, specific networking requirements and investigations into the business processes of marketing, product development, production planning, manufacturing & assembly, logistics and quality control & service. The generic model consists of (Müller et al., 2006):

- the competence of humans, arranged according to professional, methodical, social and personnel competences;
- available resources;
- the fulfilled task or executed function.

With this function a business entity is transformed and a certain performance is achieved. For a complete technical description the aspects of dimension and structure were supplemented. Function, competence, resource and marketable performance serve as criteria to further operationalise the required decomposition of the competence cell. Although E. Müller et al. differ several types of competence-cells, this paper will be limited only to the competence-cells for manufacturing and assembly.

Fig. 7. Generic model of competence cell (Müller et al., 2006)

2.1.2. Networking of competence cells

The vision of competence-cell-based networking is based on the model consisting of three levels (Figure 8) (Roth et al., 2005; Ackermann et al., 2007). From loose infrastructural and mental relations in a regional network (level I) there initially emerges an institutionalized competence network, based on competence cells (level

II). The actual creation of value takes place in a production network (level III), and the production network in this model represents virtual enterprise. It is initiated by customer needs transformed into business request.

Fig. 8. Three level model of production networks (Roth et al., 2005)

2.2 Complexity-based Model

According to G. Schuh et al. (Schuh et al., 2008) it is possible to manage dynamic reconfigurable collaborations in industry by defining generic model of complexity. Reconfigurable collaboration is a type of production network. There are several abstract complexity drivers that can cause problems in collaboration networks. The main drivers are as follows:

- uncertainty (e.g., limited information);
- dynamics (e.g., dynamic changes);
- multiplicity (e.g., a large number of participating elements and influencing factors);
- variety (e.g., many types of elements);
- interactions (e.g., communication loads);
- interdependencies (e.g., feedback loops).

G. Schuh et al. suggest modeling the dynamic behavior of a production network as a Complex Adaptive Systems (CAS) (Schuh et al., 2008). A CAS can be considered a multi-agent system with seven basic elements in which “a major part of the environment of any given adaptive agent consists of other adaptive agents, so that a portion of any agent’s efforts at adaptation is spent adapting to other adaptive agents”. Agents may represent any entity with self-orientation, such as cells, species,

individuals, enterprises or nations. Environmental conditions change, due to the agents' interactions as they compete and cooperate for the same resources or for achieving a given goal. This, in turn, changes the behavior of the agents themselves.

Furthermore, computer-based simulations can be applied to evaluate these systems. Simulations can help observing and investigating, e.g., how (potentially simple) individual behavior rules may emerge and give rise to complex (and often unpredictable) collective behavior. Additionally, the stability of these kinds of systems together with the effects of uncertainties (such as the lack of precise market forecasts as well as personal contacts) could also be evaluated by simulations.

2.3. Core Competence Cell Model

D. T. Matt (Matt, 2007), like G. Schuh (Schuh et al., 2008), is dealing with problem the structural complexity of growing organizational systems like production networks. To reduce structural complexity he reduces cells (enterprises) to three basic types: core competence cells (3C). The core competence cells are defined as:

- dealer (DL) is defined as a person or a company that buys and sells goods or services;
- producer (PR) aims at the minimization of manufacturing costs and the optimization of flexibility;
- service provider (SP) aims at "selling" his collaborators most profitably.

The central success factor of a network cell is to strictly focus on one core competence type and to force and professionalize it by entrepreneurial incentives. The different success mechanisms of DL, PR, and SP show once again that their mixing increases complexity and causes losses in efficiency. To maintain the strict core competence type focus means to inherit a cell's "success DNA" to its spin-off in the case of a cell division.

According to D. T. Matt (Matt, 2007), it can be stated that the proposed 3C model helps to reduce the entire organizational complexity from a structure perspective. It allows an organization to flexibly adapt to changing environmental conditions and thus promotes sustainable business growth within an organizational network.

3. Production Network Lifecycle

As it was mentioned, the idea of virtual enterprise differs from other types of virtual organization (Figure 3). According to L. M. Camarinha-Matos virtual organizations can be described as (Camarinha-Matos et al., 2001):

- **extended enterprise** is the closest to virtual enterprise, however it is better applied to an organization in which a dominant enterprise extends its boundaries to all or some of its suppliers (automotive industry);
- **virtual enterprise** can be seen as a more general concept including other types of organizations, namely a more democratic structure in which the cooperation is peer

to peer (i.e. extended enterprise can be seen as a particular case of virtual enterprises);

- **virtual organization** is a concept similar to a virtual enterprise, comprising a network of organizations that share resources and skills to achieve its mission / goal, but not limited to an alliance of enterprises, for example virtual organization could be a virtual municipality organization, associating via a computer network, all the organizations involved in a municipality (city hall, municipal water distribution services, internal revenue services, public leisure facilities, cadastre services, etc.);
- **networked organization** is the most general term referring to any group of organizations inter-linked by a computer network, but without necessarily sharing skills or resources, or having a common goal.

Since the virtual enterprise has been defined as a something non-hierarchical and temporary, it is important to analyze lifecycle of virtual enterprise, i.e. lifecycle of production network. Few researches have made phenomenological research of virtual enterprise lifecycle. In literature can be found virtual enterprise lifecycle of L. M. Camarinha-Matos et al. (Camarinha-Matos et al., 2001) and R. Leigh Reid et al. (Leigh Reid et al., 1996). Generally, virtual enterprise lifecycle consists of: customer request which triggers the creation of virtual enterprise, creation process, operation process and dissolution process. This generic concept of virtual enterprise lifecycle is compared to the concepts from literature (Figure 9).

Fig. 9. Virtual enterprise lifecycle

In the following table virtual enterprise lifecycle of L. M. Camarinha-Matos et al. and R. Leigh Reid et al. are mutually compared (Table 3).

Leigh Reid virtual enterprise lifecycle (<i>Leigh Reid et al., 1996</i>)	Camarinha-Matos virtual enterprise lifecycle (<i>Camarinha-Matos et al., 2001</i>)	
<p>A virtual enterprise is <i>conceived</i> when a need is recognized in the marketplace and an objective (or set of objectives) is established. This step requires understanding of the customers' expectations/needs and what it will take to satisfy them. The enterprise that is required to meet the need is visualized, and a transformation/migration strategy is articulated. This activity can be accomplished by a single firm or by an existing virtual enterprise. This step is essentially the conceptual design of a new enterprise.</p>	<p>Creation: this is the initial phase when the virtual enterprise is created / configured and for which some of the major required functionalities are: Partners search and selection, Contract Negotiation, Definition of access rights and sharing level, Join / Leave procedures definition, Infrastructure configuration, etc.</p>	
<p>The enterprise is <i>created</i> when relationships are established that will eventually bring together the requisite competencies, when a strategy is crafted and a "product" is "designed" to meet the identified need. At this stage, the firms that comprise the enterprise will likely develop and implement new or improved processes and systems to prepare for the next stages of the cycle. Activities in this stage constitute detailed design of the new virtual enterprise and complete preparation for implementation.</p>	<p>Operation: this is the phase when the virtual enterprise is performing its business process(es) in order to achieve its common goal(s), and which requires functionalities such as: Basic secure data exchange mechanisms, Information sharing and visibility rights support, Orders management, Distributed and dynamic planning and scheduling, Distributed task management, High levels of task coordination, Collaborative engineering</p>	<p>Evolution: evolutions might be necessary during the operation of a virtual enterprise when it is necessary to add and / or replace a partner, or change roles of partners. This need might be due to some exceptional event, such as (temporary) incapacity of a partner, changes in the business goal, etc. Functionalities similar to the ones specified for the creation phase are necessary to also be supported here.</p>
<p>The virtual enterprise <i>competes</i> when the "product" is offered in the marketplace. This activity may be accomplished in several ways. The enterprise may offer new or alternative solutions to previously unmet need, or it could identify, pursue and capture a defined opportunity to produce and deliver its product. Finally, the enterprise could secure new customers for existing products.</p>		
<p>After competing, the enterprise is <i>configured</i> as assets and competencies</p>		

are acquired and the requisite processes and infrastructure are deployed to accomplish the objectives of the enterprise. The assets, processes, and procedures are acquired or developed, and integrated as specified by the enterprise design to produce and deliver the required product. These activities comprise the actual implementation step for the new virtual enterprise.	support, etc.	
The virtual enterprise then <i>conducts</i> operations to produce, deliver and support the “product” and to maximize stakeholder value.		
It <i>concludes</i> operations when the objectives of the enterprise are satisfied, by terminating the relationships and by re-deploying and/or disacquiring assets.	<i>Dissolution:</i> this is the phase when the virtual enterprise finishes its business processes and dismantles itself. Two situations may be the cause for virtual enterprise dissolution, either the successful achievement of all its goals, or by the decision of involved partners to stop the operation of the virtual enterprise. The definition of liabilities for all involved partners is an important aspect that needs to be negotiated. For instance, the responsibility of a manufacturer more and more remains during the life cycle of the produced product till its disassembly and recycling.	

Tab. 3. Virtual enterprise lifecycles comparison

4. Partner Selection Problem

The problem of the selection of enterprises in production network, also known as partner selection problem (Wu et al., 1999; Fischer et al., 2004; Wu et al., 2005; Mourtzis, 2010; Ma et al., 2012; Mourtzis et al., 2010), arises when the production process is parsed to technological operations that need to be completed to produce a product. In fact it is very likely that the same technological operations can be done by two or more different cells (enterprises) in the network. The question is: which enterprise to choose? Therefore, it is obvious that, before the selection process, enterprises need to be evaluated (on the basis of their performances and competences)(Fischer et al., 2004; Mladineo et al., 2011). In this way, enterprises with the highest ratings will be selected and they will form new virtual enterprise.

Figure 10 shows a production problem, i.e. a production process with possible alternatives, and its optimal solution (Mladineo et al., 2013). The problem can be presented as a network graph that has a beginning or source (order) and end or drain (delivery). The network is formed of competence-cells (enterprises), and each technological operation is presented by cells that can perform it. Each enterprise has its rating. Higher rating is better.

Fig. 10. Alternatives of production process and its optimal solution (Mladineo et al., 2013)

According to Figure 10, for each technological operation (turning, milling or assembly) a cell (enterprise) with higher rating is selected. Hence, the production process will be realized using best combination of enterprises. The combination of enterprises is one new virtual enterprise. However, the evaluation of enterprises performances is needed to solve the problem of the selection of enterprises in production network, or partner selection problem.

Since, the partner selection problem is multicriteria problem, in this chapter a special multiple criteria decision analysis (MCDA) method is used: PROMETHEE method. However, to completely solve partner selection problem a combination of metaheuristic optimization algorithms and MCDA methods must be used. In the literature different approaches using different multicriteria methods or metaheuristics can be found: M. Fischer et al. (Fischer et al., 2004) and H. Jung (Jung et al., 2011) are using AHP (Analytic Hierarchy Process) method; G. Lanza et al. (Lanza et al., 2010) and M. Mladineo et al. (Mladineo et al., 2013) are using PROMETHEE

(Preference Ranking Organisation METHod for Enrichment Evaluations) method; F. Gao et al. (Gao et al., 2006) are using Particle swarm algorithm; C. X. Yu et al. (Yu et al., 2011) are using TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method; C. L. Chuanga et al. (Chuanga et al., 2009) F. Zhao et al. (Zhao et al., 2006) are using combination of DEA (Data Envelopment Analysis) and Genetic algorithm, and many others are using different evolutionary or multi-agent approaches (Choi et al., 2007; Wang et al., 2009; Nayak et al., 2010; Tao et al., 2010; Lanza et al., 2011; Zhang et al., 2012). It is also important to highlight the partner selection problem is more complex than similar optimization problems like the assignment problem (Wikipedia, 2013) and the job-shop problem (Wikipedia, 2013), therefore same algorithms can not be used.

4.1. PROMETHEE Method

The problem of the selection or the ranking of alternatives submitted to a multicriteria evaluation is not an easy problem, neither economically nor mathematically. Usually there is no optimal solution; no alternative is the best one on each criterion. In the recent years several decision aid methods or decision support systems have been proposed to help in the selection of the best compromise alternatives. In this chapter the PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) method was chosen for treating multicriteria problem (Brans et al., 1984; 1986; 1994). This method is known as one of the most efficient but also one of the easiest in the field. PROMETHEE method is well accepted by decision-makers because it is comprehensive and has the ability to present results using simple ranking (Brans et al., 1984).

	$f_1(.)$	$f_2(.)$		$f_j(.)$		$f_k(.)$
a_1	$f_j(a_i)$					
a_2						
...						
a_i						
...						
a_n						

Fig. 11. Input matrix for PROMETHEE method

An input for PROMETHEE method is a matrix consisting of set of potential alternatives (actions) A , where each a element of A has its $f(a)$ which represents evaluation of one criteria (Figure 11). Each evaluation $f_j(a_i)$ must be a real number.

4.1.1. Preference function

The preference structure of PROMETHEE method is based on pairwise comparisons (Brans et al., 1984; 1986; 1994). The deviation between the evaluations of two alternatives on a particular criterion is considered. For small deviations, the decision-maker will allocate a small preference to the best alternative and even possibly no preference if he considers that this deviation is negligible. The larger the deviation is, the larger the preference is. There is no objection to consider that these preferences are real numbers varying between 0 and 1. This means that for each criterion the decision-maker has in mind a function:

$$P_j(a,b) = F_j[d_j(a,b)] \quad (1)$$

where:

$$d_j(a,b) = f_j(a) - f_j(b) \quad (2)$$

and for which:

$$0 \leq P_j(a,b) \leq 1 \quad (3)$$

In case of a criterion to be maximized, this function is giving the preference of a over b for observed deviations between their evaluations on criterion $f_j()$. It should have the following shape (Figure 12).

Fig. 12. Preference function

The preferences equal 0 when the deviations are negative. The following property holds:

$$P_j(a,b) > 0 \Rightarrow P_j(b,a) = 0 \quad (4)$$

For criteria to be minimized, the preference function should be reversed or alternatively given by:

$$P_j(a, b) = F_j[-d_j(a, b)] \quad (5)$$

The pair $\{f_j(), P_j(a, b)\}$ is the generalized criterion associated to criterion $f_j()$. Such a generalized criterion has to be defined for each criterion. In order to facilitate the identification six types of particular preference functions have been proposed (Table 4) (Brans et al., 1984; 1986; 1994).

Generalized criterion	Definition	Preference function	Parameters
Usual	$P(d) = \begin{cases} 0, & d = 0 \\ 1, & d \neq 0 \end{cases}$		-
U-shape	$P(d) = \begin{cases} 0, & d < q \\ 1, & d \geq q \end{cases}$		q
V-shape	$P(d) = \begin{cases} \frac{ d }{p}, & d < p \\ 1, & d \geq p \end{cases}$		p
Level	$P(d) = \begin{cases} 0, & d < q \\ 0.5, & q < d < p \\ 1, & d > p \end{cases}$		q, p
V-Shape with indifference	$P(d) = \begin{cases} 0, & d < q \\ \frac{ d - q}{p - q}, & q < d < p \\ 1, & d > p \end{cases}$		q, p
Gaussian	$P(d) = 1 - e^{-\frac{d^2}{2\sigma^2}}$		σ

Tab. 4. Types of generalized criteria (preference functions)

4.1.2. PROMETHEE I and PROMETHEE II

First, method PROMETHEE I ranks actions by a partial pre-order, with the following dominance flows (Figure 13) (Brans et al., 1984; 1986; 1994):

leaving flow: $\Phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \Pi(a, x)$ (6)

entering flow: $\Phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \Pi(x, a)$ (7)

where a denotes a set of actions, n is the number of actions and Π is the aggregated preference index defined for each couple of actions. The PROMETHEE I method gives the partial relation.

Fig. 13. PROMETHEE I partial pre-order

Then, a net outranking flow is obtained from PROMETHEE II method which ranks the actions by total pre-order (Figure 14) (Brans et al., 1984; 1986; 1994):

net flow: $\Phi(a) = \Phi^+(a) - \Phi^-(a)$ (8)

In the sense of priority assessment net outranking flow represents the synthetic parameter based on defined criteria and priorities among criteria. Usually, criteria are weighted using criteria weights w_j and usual pondering technique:

$$\Pi(a, b) = \frac{\sum w_j P_j(a, b)}{\sum w_j} \quad (9)$$

Furthermore, different sets of criteria weights can be used and then each set represents one scenario. And usually MCDA problems have more than one scenario.

Fig. 14. PROMETHEE II total pre-order

4.1.3. Example of usage of PROMETHEE method

Here the PROMETHEE method is demonstrated on the problem of selection of location for new power plant. There are 6 different locations (alternatives) and there are 3 criteria: manpower (number of personnel), power of power plant (MW) and cost of construction (M€). For each criterion preference function and all parameters are chosen (Figure 15). Problem is solved by PROMETHEE I method (Figure 16) and PROMETHEE II method (Figure 17) using special software called *Visual PROMETHEE*(<http://www.promethee-gaia.net/>). The weight for each criteria is determined by group of experts.

	<div>Scenario1</div>		<div>Manpower</div>	<div>Power</div>	<div>Construction</div>
	Unit		persons	MW	M€
	Cluster/Group				
	Preferences				
	Min/Max		min	max	min
	Weight		0,20	0,40	0,40
	Preference Fn.		U-shape	V-shape	Linear
	Thresholds		absolute	absolute	absolute
	- Q: Indifference		10	n/a	50
	- P: Preference		n/a	300	500
	- S: Gaussian		n/a	n/a	n/a
	Statistics				
	Evaluations				
☒	<div>Italy</div>		80	900	600
☒	<div>Belgium</div>		65	580	200
☒	<div>Germany</div>		83	600	400
☒	<div>Sweden</div>		40	800	1000
☒	<div>Austria</div>		52	720	600
☒	<div>France</div>		94	960	700

Fig. 15. Input matrix for the problem

Fig. 16. PROMETHEE I partial pre-order of locations

Fig. 17. PROMETHEE II total pre-order of locations

5. Solving Partner Selection Problem

Special case of virtual enterprise evaluation occurs when partners are *a priori* selected (Mladineo et al, 2013), i.e. some of enterprises are willing to be part of new virtual enterprise, and some are not. In this special case it is possible to have small number of different combinations of partners of new virtual enterprise. So there is need to mutually compare couple of virtual enterprises. It rises following questions: Which virtual enterprise is the best one? How much is one virtual enterprise better than others? The first question is ranking problem, and the second question is sorting problem (Mladineo et al, 2013). However, pre-requisition of virtual enterprise evaluation is the evaluation of enterprises that can be part of new virtual enterprise.

5.1. Enterprise Evaluation

To evaluate and rank enterprises it is necessary to design a set of criteria that will represent all the important parameters which need to be taken into account when performing ranking. It should be primarily taken into account that there are parameters that change each time when a new production network is formed for a new product, and there are parameters that do not change so often. Therefore, a set of criteria which will be used can be divided into two sets (Mladineo et al, 2011),:

- **dynamic criteria:** criteria whose values change for each enterprise depending upon the offer for particular product production or development (an example of such criteria is the price of the product);
- **static criteria:** criteria whose values do not change so often, or at most a few times a year (an example of such criteria is a technology of enterprise).

A set of dynamic criteria includes offer that enterprise offered when a new production network for a new product is formed. That offer is usually made up of two elements: the price per piece and the day of delivery. Static set of criteria can be further divided onto :

- **competence criteria:** criteria covering all the competencies of the enterprise: technical, organizational and human competence;
- **economic criteria:** criteria that consider economic feasibility or risk of involving enterprise into production network;
- **sociological criteria:** criteria which analyze sociological impact of involving certain enterprise in the production network.

After criteria and their parameters have been determined, an input matrix for PROMETHEE method, i.e. criteria evaluation for each action (enterprise), is made using data gathered in special questionnaire. This questionnaire was sent to the production enterprises of Split-Dalmatia County. In the following figures (Figure 18 and Figure 19) an input matrix for 7 enterprises is shown. However, star names are used instead of real names of enterprises.

ID	Name	Dynamic criteria		Static criteria						
				Competence criteria						
		Price per piece	Delivery day	Technology	References	Information system	Employees qualification	Employees specialist level	Quality certificate	Continuous improvement
		Minimum €	Minimum Day	Maximum 0-5 grade	Maximum 0-5 grade	Maximum 0-5 grade	Maximum 0-6 grade	Maximum 0-5 grade	Maximum 0 - 1 (no - yes)	Maximum 0-5 grade
1	Alpha Centauri	103	31	4	1	1,5	2	4	1	1
2	Beta Ursae Minoris	102	33	4	2	1	3	3	1	1
3	Alpha Ophiuchi	110	33	4	3	0,5	3	0	1	1
4	Beta Aquarii	115	35	4	4	2	4	2	1	1
5	Alpha Orionis	116	32	3	2	0,5	3	4	1	1
6	Alpha Virginis	111	33	4	1	1,5	3	3	1	1
7	Delta Leonis	100	35	2	2	3,5	2	2	0	2

Fig. 18. Input matrix for dynamic and competence criteria

ID	Name	Static criteria				
		Economic criteria			Sociological criteria	
		Deadline reliability	Network cooperation	Financial reliability	Number of employees	Area of special state care
		Maximum 0-5 grade	Maximum 0-5 grade	Maximum 0-5 grade	Maximum Employee	Maximum 0 - 1 (no - yes)
1	Alpha Centauri	5	2	5	90	0
2	Beta Ursae Minoris	4	3	4	300	0
3	Alpha Ophiuchi	5	0	5	30	1
4	Beta Aquarii	5	3	5	25	0
5	Alpha Orionis	4	3	4	190	0
6	Alpha Virginis	5	1	5	80	0
7	Delta Leonis	4	1	4	1300	0

Fig. 19. Input matrix for economic and sociological criteria

PROMETHEE method was performed using 4 different predefined scenarios (Figure 20). A set of weights for each scenario was determined by experts. Criteria preference function type and preference thresholds were obtained using in-built function “*Preference Function Assistant*” of *Visual PROMETHEE* software. Following results were obtained (Figure 21 and Figure 21).

		Product complexity	
		Simple	Complex
Size of series	Small	Scenario A	Scenario B
	Large	Scenario C	Scenario D

Fig. 20. Different scenarios for different complexity of product and/or production

Fig. 21. Ranking results and criteria weights for scenario A and B

Fig. 22. Ranking results and criteria weights for scenario C and D

This analysis showed that 3 enterprises (*Beta UrsaeMinoris*, *Alpha Ophiuchi* and *Beta Aquarii*) are dominant in comparison with other enterprises. However, in different scenarios these 3 enterprises are taking turns at the top. For example: for simple product and small series the best enterprise to realize that production process is *Alpha Ophiuchi*. However, for complex product and large series the best enterprise to realize that production process is *Beta UrsaeMinoris*.

5.2. Virtual Enterprise Evaluation

Special case of virtual enterprise evaluation, when partners are *a priori* selected, will be analyzed on example of virtual enterprise for simple production process. For

Name of VE	Milling	Drilling	Counter-sinking	Threading
VE-1	E1	E1	E5	E5
VE-2	E10	E7	E8	E8
VE-3	E4	E9	E5	E9

Tab. 5. Virtual enterprises formed a priori

For each enterprise criteria evaluations are made depending on bid (i.e. cost) and rating (quality level) of every enterprise (Table 6).

Enterprise ID	C1 Cost	C2 Rating
E1	32 k€	60 %
E2	34 k€	81 %
E3	29 k€	87 %
E4	31 k€	77 %
E5	27 k€	54 %
E6	33 k€	49 %
E7	30 k€	68 %
E8	29 k€	44 %
E9	28 k€	57 %
E10	31 k€	91 %
E11	33 k€	63 %
E12	30 k€	72 %

Tab. 6. Criteria evaluations for enterprises

Finally, criteria evaluations for each virtual enterprise are calculated using sum for cost and transport criteria, and average for rating criteria (Table 7).

Name of VE	C1 Cost (Min)	C2 Rating (Max)	C3 Transport (Min)
VE-1	118 k€	57,0 %	67 km
VE-2	119 k€	61,8 %	74 km
VE-3	114 k€	61,3 %	89 km

Tab. 7. Criteria evaluations for virtual enterprises

These three virtual enterprises were compared using PROMETHEE method. A weight for each criterion was determined by experts. Criteria preference function type and preference thresholds were obtained using in-built function “*Preference Function Assistant*” of *Visual PROMETHEE* software. Following results were obtained (Figure 26).

Fig. 26. Result of ranking three virtual enterprises using determined criteria weights

From Figure 26 it is clear that the best virtual enterprise is VE-2. However, how much better is VE-2 than VE-3 and VE-1?

It is a problem of sorting, not just ranking. To calculate how much is VE-2 really better, it is important to compare all three virtual enterprises with optimal and anti-optimal solution of production process presented on Figure 3. It is similar to ideal and anti-ideal alternative used in TOPSIS method (Yu et al., 2011). However, in TOPSIS method ideal and anti-ideal alternative are fictional, but optimal and anti-optimal solution of production process are real alternatives (Table 8 and Figure 27).

Name of VE	Milling	Drilling	Counter-sinking	Threading
VE-Optimum	E10	E9	E5	E5
VE-Pessimum	E6	E11	E6	E6

Tab. 8. Optimal (optimum) and anti-optimal (pessimum) alternative

Fig. 27. Virtual enterprises formed a priori and pessimum / optimum virtual enterprise

Now, final virtual enterprise evaluation matrix can be made (Table 9).

Name of VE	C1 Cost (Min)	C2 Rating (Max)	C3 Transport (Min)
VE-Optimum	113 k€	64,0 %	48 km
VE-1	118 k€	57,0 %	67 km
VE-2	119 k€	61,8 %	74 km
VE-3	114 k€	61,3 %	89 km
VE-Pessimum	132 k€	52,5 %	120 km

Tab. 9. Final virtual enterprise evaluation matrix

Again, these virtual enterprises were compared using PROMETHEE method. Same criteria weights, type of preference function and preference thresholds were used. Following results were obtained (Figure 28 and Figure 29).

Fig. 28. Result of ranking and sorting virtual enterprises using bar chart

Fig. 29. Result of ranking and sorting virtual enterprises using PROMETHEE diamond

After sorting virtual enterprises (Figure 29), it is clear that all three virtual enterprises mutually compared are very similar, and they are all much closer to the optimal alternative than the anti-optimal alternative. VE-2 and VE-3 are especially very similar alternatives (Figure 28), and only after sorting it was possible to clearly see that fact.

6. Conclusion

In this chapter the optimization of selection of enterprises in production network was achieved using multi criteria decision analysis: PROMETHEE method. An evaluation and comparison of enterprises has been achieved. It is clearly shown that, using PROMETHEE method, enterprises can be evaluated taking into account their competences, i.e. what enterprise possesses in the terms of technology, references, information system, etc. Hence, economic and sociological criteria can also be added into analysis. A special scenario portfolio was created for different complexity of product and/or production process. On the case study with real enterprises, it is shown that different scenarios will produce different enterprise as the best one. So it is very important for production network manager to carefully choose criteria weights and form proper scenarios. This could be done by interviewing experts. The evaluation and comparison of enterprises was pre-requisition to evaluate, compare and rank virtual enterprise.

A special case of virtual enterprise evaluation, when partners are *a priori* selected, has been analyzed. The difference between ranking and sorting is demonstrated on the example. It has been shown that sorting of alternatives is very important to get clear picture about real difference between alternatives (virtual enterprises).

7. Future Challenges

Production networks represent future of manufacturing; especially they represent possible solution for the new production-organizational paradigm "Production as a Service". This new paradigm intends to fulfill very specific needs and requirements of modern customer, i.e. to produce one piece of specific product for only one customer.

For instance, if a customer needs a special custom made motorcycle (*Figure 30*), he can buy only a similar motorcycle from motorcycle producer for reasonable price. If the customer wants exactly the same motorcycle as imagined one, he needs to buy it from custom made motorcycle producer. However, the price will not be reasonable, it will be very expensive. A custom made motorcycle for reasonable price is something that only production network can produce. And it represents main competitive advantage of production networks. But it also shows that production networks can function like "Production as a Service".

However, production networks are virtual organizations and there is a problem of stability of such an organizational formation. So the key challenge is to have production network formed of good and trustful enterprises, i.e. partners. And that is the reason why solving of partner selection problems is one of the key challenges for successful management of production networks.

In further researches focus will be on solving more complex production processes, and on determination of criteria weights and other criteria parameters, usage of criteria weights stability intervals analysis, etc. Focus will also be on the design of fast and accurate algorithms for solving partner selection problems. Today's algorithms are taking lot of time to solve complex production processes. In the future this needs to be solved to be as fast as a web service used in web application for management of production network.

Fig. 30. Competitive advantage of production network

It is also important to highlight that the management of production networks requires knowledge about information technology and it also requires knowledge about some management tools like multiple criteria decision analysis. All these issues need to be taken into account when drawing a path into the research area of production networks.

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