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SUSTAINABILITY THROUGH PRODUCTION NETWORKS

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Abstract
Global economic crisis has brought into question sustainability of many industrial enterprises, especially Large-sized Enterprises (LEs). However, the strength of the European economy are not Large-sized Enterprises, but Small and Medium-sized industrial Enterprises (SMEs). As an alternative to LEs there is networking of SMEs into flexible production networks. Inside production network SMEs can collaborate on new product development forming Virtual Enterprise. SMEs collaborating as one Virtual Enterprise can be seen as a sustainable Large-sized Enterprise. However, to achieve sustainability through production networks, i.e. Virtual Enterprises, it is essential to choose an optimal combination of SMEs in Virtual Enterprise formation process. Since it is a complex task that requires the use of multi-criteria decision-making methods, in this paper PROMETHEE method is used.

Keywords
production systems, multiobjective optimizations, decision making, processes, networks.

Introduction

Global economic crisis is forcing researchers to seek for new flexible business-organizational structures which can achieve long term sustainability. Such a flexible business-organizational structure can be formed by networking Small and Medium-sized Enterprises (SMEs) into production networks. The only pre-requirement is that every SME of a production network is capable to be part of special collaboration inside network called Virtual Enterprise (VE). Virtual Enterprise formation process begins when customer needs are recognized on the market and new product development has started to fulfill recognized needs. For each new product a new Virtual Enterprise is formed from different SMEs (Fig. 1).

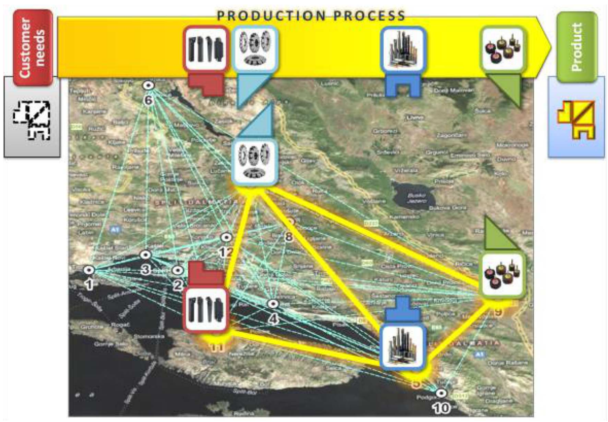

Fig. 1. Formation of Virtual Enterprise inside production network.

SMEs are often seen as a backbone of European economy. In 2011, to stimulate research and development of production networks, European Union has funded six FP7 projects with more than 37 million € budget: *ADVENTURE*, *BIVEE*, *ComVantage*, *GloNet*, *IMAGINE*, and *VENIS*.

According to the EU regulations, an 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.

SMEs collaborating as one Virtual Enterprise can be seen as a sustainable Large-sized Enterprise. However, to achieve sustainability through production networks, i.e. Virtual Enterprises, it is essential to choose an optimal combination of SMEs in Virtual Enterprise formation process.

Virtual Enterprise

According to [1] Virtual Enterprise (VE) 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. Clearly, there is a tendency to describe a VE 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 organization without forming a new legal entity nor establishing a physical headquarter. In other words, VE materialize through the integration of skills and assets from different firms into a single business entity.

The idea of VE differs from other types of virtual organization. According to [1] virtual organizations can be described as:

- *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, cadaster 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.

Virtual Enterprise lifecycle

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 researchers have made phenomenological research of VE lifecycle [1–2]. Generally, VE lifecycle consists of: customer request (which triggers the formation of VE), creation process, operation process and dissolution process (Fig. 2).

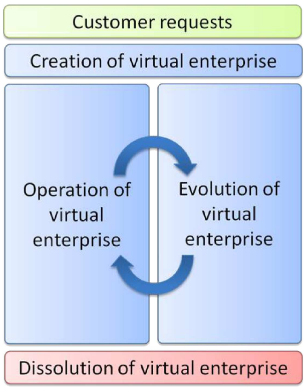

Fig. 2. Virtual Enterprise lifecycle.

Virtual Enterprise formation process

In the initial phase of Virtual Enterprise formation process it is important to identify activities which need to be performed to develop and produce new product. For instance, it is important to identify all technological processes of production process and identify which production enterprises can realize one of the technological processes. That problem is called: partner selection problem [3–5], and it is very similar to supplier selection problem [6].

Optimization of partner selection problem can be solved using metaheuristics [3–5]. So it is possible to find optimal solution – optimal combination of partners (enterprises), i.e. it is possible to find optimal enterprise for each technological process. However, such an optimization problem is multi-criteria problem, since many criteria are used to evaluate enterprises. Criteria like: price, time of delivery, quality of enterprise, etc. [7–8]. Once criteria and criteria parameters are defined, and evaluations for each criterion are made, a method for multi-criteria analysis and decision-making can be used to rank alternatives. A method suitable for this kind of Multi-Criteria Decision-Making (MCDM) [9, 10] is PROMETHEE method.

Finally, "best" alternatives, i.e. "best" Enterprises, are selected to be partners in a new Virtual enterprise to develop and produce a new product. Virtual Enterprise legally does not exist, but it exists as virtual production system which is fulfilling customer needs.

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 single 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 paper the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method was chosen for treating multicriteria problem [9]. This method is known as one of the most efficient but also one of the easiest that can be used for this purpose. PROMETHEE method is well accepted by decision-makers because it is comprehensive and has the ability to present results using simple ranking [9].

An input for PROMETHEE method is a matrix consisting of a set of potential alternatives (actions) A, where each a element of A has its $f(a)$ which represents evaluation of one criterion (Fig. 3). Each evaluation $f_j(a_i)$ must be a real number.

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

Fig. 3. Input matrix for PROMETHEE method.

Preference function

The preference structure of PROMETHEE method is based on pairwise comparisons [10]. 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:

$$P_j(a,b) = F_j\left[d_j(a,b)\right], \tag{1}$$

where

$$d_j(a,b) = f_j(a) - f_j(b) \tag{2}$$

and for which:

$$0 \le P_j(a,b) \le 1. \tag{3}$$

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 (Fig. 4).

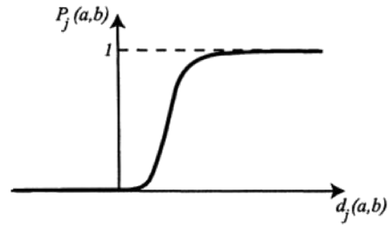

Fig. 4. Preference function.

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

$$P_j(a,b) > 0 \Rightarrow P_j(b,a) = 0. \tag{4}$$

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

$$P_j(a,b) = F_j\left[-d_j(a,b)\right]. \tag{5}$$

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 preference functions have been proposed (Table 1) [10].

Table 1
Types of generalized criteria (preference functions).

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

PROMETHEE I and PROMETHEE II

Method PROMETHEE I ranks actions by a partial pre-order (Fig. 5), with the following dominance flows [10], for leaving flow:

$$\Phi^+(a) = \frac{1}{n-1}\sum\nolimits_{x\in A}\Pi(a,x) \tag{6}$$

and for entering flow:

$$\Phi^-(a) = \frac{1}{n-1}\sum\nolimits_{x\in A}P(x,a), \tag{7}$$

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.

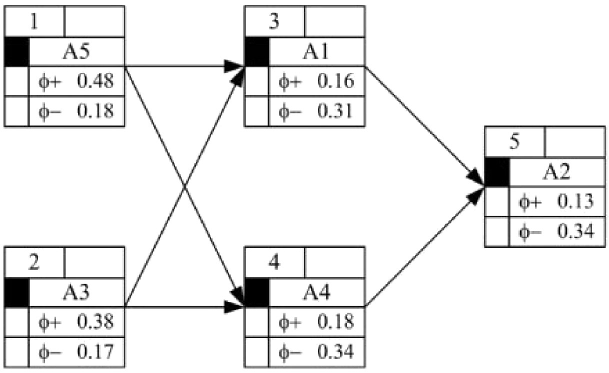

Fig. 5. PROMETHEE I partial pre-order.

The PROMETHEE I method gives the partial relation, and then a net outranking flow is obtained from PROMETHEE II method which ranks the actions by total pre-order (Fig. 6) calculating net flow [10]:

$$\Phi^{(}a) = \Phi^+(a) - \Phi^-(a). \tag{8}$$

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:

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

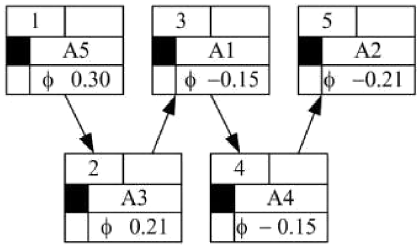

Fig. 6. PROMETHEE II total pre-order.

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.

Virtual Enterprise evaluation

Virtual Enterprise evaluation will be analyzed on example of simple production process. For analysis and discussion a partner selection problem presented on (Fig. 7) is used. Data on enterprises forming the production network used in this example are presented on (Fig. 8).

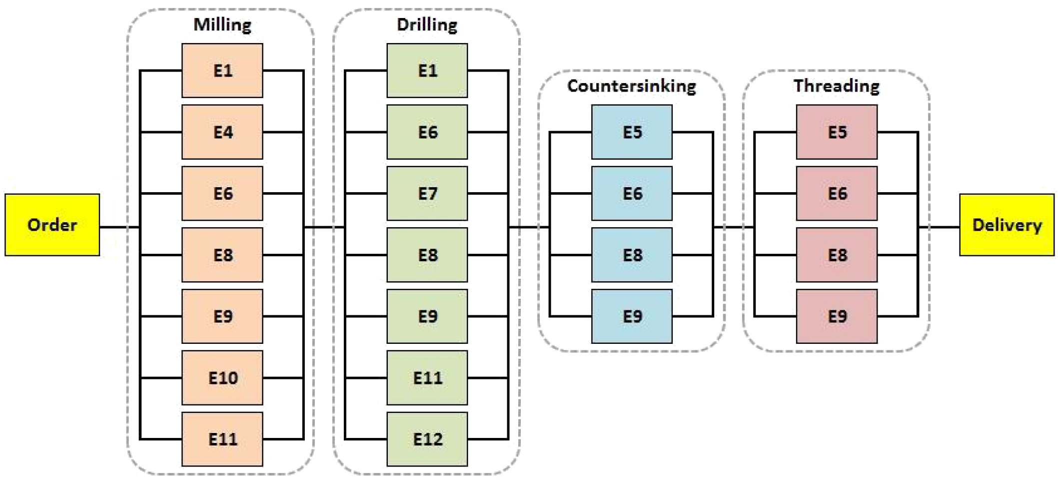

Fig. 7. Partner selection problem – many alternatives for each technological process.

ID	Distances												Competences of enterprise	Rating
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12		
E1	0	17	11	36	67	45	37	40	78	73	28	27	Sawing, Milling, Turning, Drilling, Grinding, Assembly	60%
E2	17	0	7	20	51	44	25	24	62	58	16	12	Grinding, Painting, Assembly	81%
E3	11	7	0	27	58	40	26	29	68	65	23	16	Painting, Assembly	87%
E4	36	20	27	0	31	57	29	20	43	39	13	18	Milling, Turning, Assembly	77%
E5	67	51	58	31	0	84	54	42	23	8	39	48	Sawing, Grinding, Countersinking, Reaming, Threading, Painting, Assembly	54%
E6	45	44	40	57	84	0	30	42	84	92	60	39	Milling, Turning, Drilling, Grinding, Countersinking, Reaming, Threading, Painting, Assembly	49%
E7	37	25	26	29	54	30	0	12	54	62	35	13	Turning, Drilling, Grinding, Assembly	68%
E8	40	24	29	20	42	42	12	0	44	50	29	12	Milling, Turning, Drilling, Grinding, Countersinking, Reaming, Threading, Painting, Broaching, Sawing, Assembly	44%
E9	78	62	68	43	23	84	54	44	0	25	54	54	Milling, Drilling, Countersinking, Reaming, Threading, Grinding, Assembly	57%
E10	73	58	65	39	8	92	62	50	25	0	45	55	Milling, Assembly	91%
E11	28	16	23	13	39	60	35	29	54	45	0	22	Sawing, Milling, Turning, Drilling, Grinding, Assembly	63%
E12	27	12	16	18	48	39	13	12	54	55	22	0	Sawing, Turning, Drilling, Assembly	72%

Fig. 8. Data on enterprises of production network

Special case of Virtual Enterprise evaluation occurs when partners are *a priori* selected [7], i.e. some of enterprises are willing to be part of new virtual enterprise, and some are not willing. In this special case it is possible to have small number of different combinations of partners of new Virtual Enterprise. So there is a need to mutually compare couple of Virtual Enterprises. Following questions appear: Which VE is the best one? How much is one VE better than others? The first question is ranking problem [11], and the second question is sorting problem.

In an example analyzed in this paper, couple of Virtual Enterprises will be *a priori* selected. These VEs will be mutually compared, ranked and sorted; using three different criteria.

For production process presented on Fig. 7 following Virtual Enterprises are *a priori* formed (Fig. 9 and Table 2).

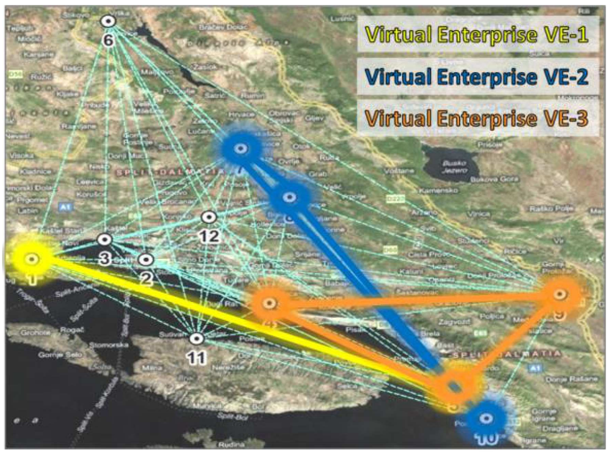

Fig. 9. Virtual enterprises formed *a priori*.

For each enterprise criteria evaluations are made depending on bid (i.e. cost) and rating (quality level) of every enterprise (Table 3).

Table 2
Virtual enterprises formed *a priori*.

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

Table 3
Criteria evaluations for enterprises.

Enterprise ID	C1 Cost	C2 Rating
*E*1	32 k€	60%
*E*2	34 k€	81%
*E*3	29 k€	87%
*E*4	31 k€	77%
*E*5	27 k€	54%
*E*6	33 k€	49%
*E*7	30 k€	68%
*E*8	29 k€	44%
*E*9	28 k€	57%
*E*10	31 k€	91%
*E*11	33 k€	63%
*E*12	30 k€	72%

Finally, criteria evaluations for each Virtual Enterprise are calculated using sum for cost and transport criteria, and average for rating criteria (Table 4).

Table 4
Criteria evaluations for Virtual Enterprises.

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

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 [12]. Following results were obtained (Fig. 10).

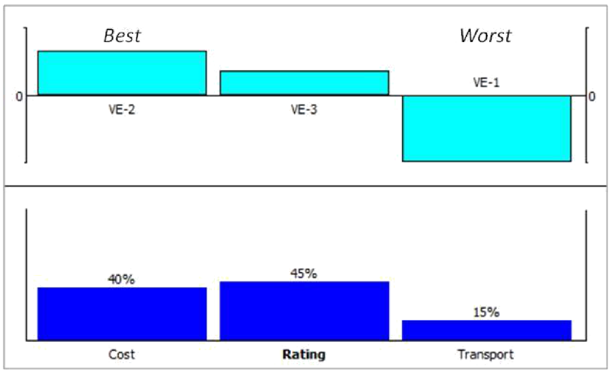

Fig. 10. Result of ranking three Virtual Enterprises using determined criteria weights.

According to Fig. 10 it is clear that the best Virtual Enterprise is *VE-2*. However, how much is *VE-2* better 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. It is similar to ideal and anti-ideal alternative used in TOPSIS method [13]. However, in TOPSIS method ideal and anti-ideal alternative are fictional, but optimal and anti-optimal solution of production process are real alternatives (Table 5 and Fig. 11).

Table 5
Optimal (optimum) and anti-optimal (pessimum) alternative.

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

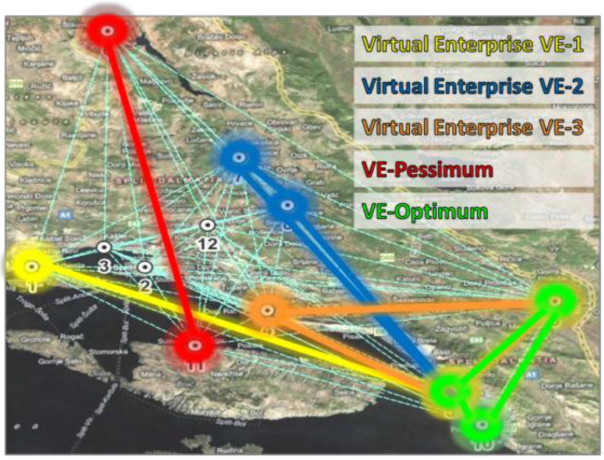

Fig. 11. Virtual enterprises formed *a priori*, pessimum and optimum Virtual Enterprise.

Now, final virtual enterprise evaluation matrix can be built (Table 6).

Table 6
Final Virtual Enterprise evaluation matrix.

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

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 (Fig. 12 and Fig. 13).

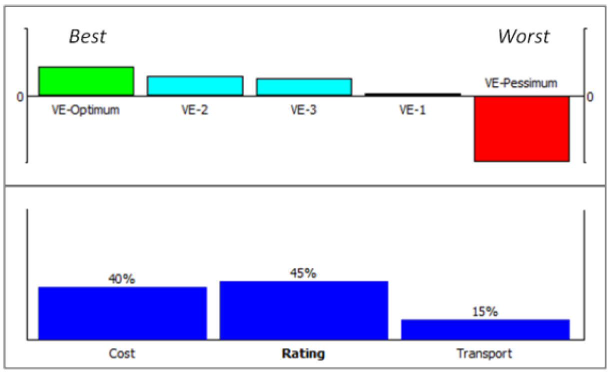

Fig. 12. Result of ranking and sorting virtual enterprises using bar chart.

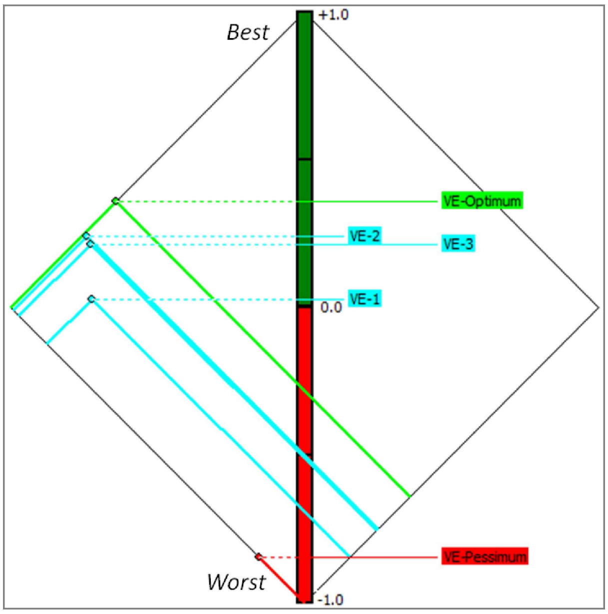

Fig. 13. Result of ranking and sorting of Virtual Enterprises using PROMETHEE diamond.

After sorting of Virtual Enterprises (Fig. 12), it is clear that all three virtual enterprises mutually compared are very similar, and they are all very close to the optimal alternative than the anti-optimal alternative. VE-2 and VE-3 are especially very similar alternatives (Fig. 12), and only after sorting it was possible clearly see that fact.

This kind of approach to Virtual Enterprise evaluation can result in selection of Virtual Enterprise with high level of fitness. And such a Virtual Enterprise should be sustainable for a long term. In that way sustainable production through production networks can be achieved.

Conclusions

In this paper an evaluation and comparison of Virtual Enterprises have been achieved using PROMETHEE method. A special case of Virtual Enterprise evaluation, when partners are *a priori* selected, has been analyzed. The difference between ranking and sorting was demonstrated on the example. It has been shown that sorting of alternatives is very important to get clear picture about realistic difference between alternatives (Virtual Enterprises). In the case of Virtual Enterprises this is also important, because only Virtual Enterprise with high level of fitness can be sustainable for a long term. Only that way sustainable production through production networks can be achieved.

In further research a focus will be on solving more complex production processes, usage of criteria weights, stability intervals analysis, etc.

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