Abstract: This paper describes the issues of searching and selection of partners in distributed manufacturing systems (DMS). For solving of this problem the multi-criteria optimization algorithm using Monte Carlo method is proposed. The development of the multi-criteria optimization algorithm (MOA) to support the configuration of DMS in the virtual breeding environment (VBE) is described specifically. The proposed model deals with the minimization of fixed and variable costs and compliance of the due date.

Key words: Distributed Manufacturing System (DMS), Multi-criteria Optimization Algorithm (MOA), Virtual Breeding Environment (VBE), Monte Carlo

1. INTRODUCTION

In the age of globalization and the continued development of information and communication technologies (ICT), manufacturing is entering a new era in which the time-to-market significantly reduced in addition to continuous changes in products and customer orientation. This era is characterized by continuous changes in products and customer orientation whereas time-to-market is greatly reduced. If manufacturers want to keep up with competitive environment they are forced to develop more complex and agile products in shortest possible time and for lowest possible costs. However, for most of them, these requirements are too difficult to fulfill within their own capacity, know-how, and financial resources.

It is clear that development and manufacturing of products includes increasing number of manufacturers, suppliers, subcontractors, distributors or customers which implies increasing need for establishing joint partnerships. Dispersion of production functions, the development of information and communication technologies and customer orientation have become one of the main factors that contributed to the emergence of new organizational structures, such as virtual organization (VO) / Distributed Manufacturing System (DMS), which have over traditional organizations several advantages as a flexible structure and rapid response to market changes. It is obvious that choosing the right partners is essential for the successful establishment and operation effectiveness of DMS. Selection of partners in DMS is currently constantly studied in various scientific papers. This paper deals with the problem of search the partners in the Virtual Breeding Environment (VBE) and their selection to the DMS. In particular, the selection of partners to support the DMS using the multi-objective optimization methods based on Monte Carlo algorithm is studied.

The rest of the paper is organized as follows. The second chapter presents an overview of the current state of the art of searching and selecting partners on intercorporate level. The third chapter describes the methodology for the selection of partners in the DMS, limiting conditions and the definition of optimization methods to support the selection of partners. Also in this chapter an illustrative example is
presented to show the application of the proposed algorithm. The last chapter presents the achievements and areas for further research.

2. BACKGROUND

Despite the literature and Internet sources offer several types of alternative terminology, the term of distributed manufacturing systems is widely accepted not only in industry but also in academia sphere. Represents a grouping of geographically distant and systemically integrated companies involved in the creation of a common product. The basic difference between classical and DMS business is in a distributed deployment of participants and information processing. The present author defines distributed manufacturing systems (virtual organizations) as follows:

"Virtual Organization (DMS) is a temporary association of companies that are formed in order to exploit changing market opportunities. In virtual organizations, individual companies can share costs, expertise and market access, each of which is involved in co-operation in the most efficient manner." (Byrne, J.A., Brandt, R. & Port, O., 1993, p. 36) [1]

All definitions DMS / VO can be found in the literature [2].

Based on the available definitions it is possible to identify a set of common characteristics of DMS:

- The aim of DMS is utilize business opportunities, to increase competitiveness and profit making.
- It is a temporary consortium - resulting in a relationship between the control company and its partner companies.
- Companies use information and communication technologies (ICT).
- They are variously geographically and culturally distributed.
- There is a management company - usually the one that saw a business opportunity, providing search, selection and management of partner companies.
- Structure and partners of DMS are product-oriented.
- Interested companies should be presented to a third party as a unified organization.
- Grouped enterprises can dynamically change or maintain its stability.
- Each of the participating companies are involved in co-operation in the most efficient way.

On the basis of shared characteristics the new DMS definition can be created as follows:

"Distributed manufacturing system can be characterized as a temporary linked businesses, institutions or individuals, culturally diverse to each other, geographically distributed and interconnected through information and communication technologies in order to exploit business opportunities. The managing company provides searching, selecting and managing of partner companies which are involved in co-operation in the most efficient manner."

DMS members cooperate and jointly take advantage of business opportunities that, given its market position have not been able to achieve.

Successfully meeting the needs of customers requires effective cooperation and coordination between partners. Businesses should be prepared to work at the moment of finding a business opportunity. The underlying assumption of preparedness is a long term cooperation "participation" in the joint associations of undertakings, also referred to as a virtual breeding environment (VBE). According to (Afsarmanesh, Camarinha-Matos, [3]), VBE can be characterized as:

"Association of organizations and their supporting institutions that have adopted an agreement on long-term cooperation, adopt a common operating principles and infrastructures in order to increase their potential and readiness for cooperation."

VBE is an open but controlled limited association of undertakings. Its main objective is to improve the readiness of...
member companies to join the DMS. In addition, VBE can include other types of organizations such as (research institutes, universities, associations, development centres, state-sponsored organizations, etc.).

2.1 Related work
Based on the literature review, it was observed that until 2002 there was not clear criteria for selecting partners to DMS consortium and also was not fully understood the whole process of DMS design. As regards the process of forming DMS, Carvalho et al. (2003) proposes dividing the process of DMS design in four activities: specification and analysis of business opportunities, partner search, selection of partners and generate work breakdown in DMS. With regard to selection criteria, this work also does not constitute a significant improvement. In this case, DMS designer uses information obtained by the broker to select the organizations which better meet the demands of CO. Camarinha-Matos et al. (2005b) presented a much more detailed process of DMS design, which identified seven different activities: identification and characterization of CO, DMS rough plan, search and selection of partners, negotiation, detailed planning of DMS, contracts and run the DMS [4].

When selecting partners in DMS for the business opportunity, there are many factors to be taken into account. These factors include price, quality, trust, product delivery time, reliability, and more. However, key factors that need to be addressed include cost and time. As pointed out by Jagdev and Browne [5], high quality products is necessary but not sufficient condition for market entry, which implies that the cost and time-to-market can be considered as a basis of competitive advantage. In a study of Brucker et al. [6], the issue of partner selection is part of the planning project. In the study of Wang et al. [7] the cost and time of completion of the subproject are taken into account and genetic algorithm is used for problem solution.

In DMS, partners are diverse cultures and are geographically distributed, therefore besides the cost and time required for performing the manufacturing tasks, transportation costs and times can't be ignored. These costs and time are so important that it cannot be ignored. With the transportation cost and time considered, the partner selection problem is much more complicated. Taking the processing cost and the transportation cost into account, Wu et al. [8] modelled the partner selection problem by a network model and an efficient algorithm was presented to solve it. However, in that model, the time factor is neglected.

In order to minimize transportation and subprojects costs Wu et al. [8] proposed an integer programming method for solution of network partner selection. Ip et al. [9] studied the problem of partner selection and proposed integer based program. This model is similar to the model of project planning with due dates and to find optimal solutions the B&B algorithm is used. Addressing the selection of partners this is not easy task due to the inherent complexity of the problem such as imposed restrictions, discrete decisions, different cost structures and risk factors. The complexity of the problem has been described by many researchers to develop various heuristic algorithms, which are for example taboo search algorithm [10], genetic algorithm [11], B&B algorithm [12] and exchange procedure [13] to find the nearest optimal solution for different variants of the problem of partner selection. The number of researchers are addressing the problem of selection of partners used quantitative analytical methods [14, 15], but quantitative analytical methods are still a challenge. In the case of DMS mathematical formulation and module designs optimization methods of selecting the right partners is very important.
3. EXAMPLE OF PARETO MULTI-OBJECTIVE (MO) OPTIMIZATION OF PARTNER SELECTION PROBLEM

Suppose that the attractive business opportunity has been detected. However, enterprise which detected this business opportunity doesn't have sufficient capacity to ensure the manufacture process, assembly and distribution of the product it decided to build a DMS. During the design process of DMS, managing company divides project into the several subprojects and tries to select optimal partners for each subproject.

Fig. 1. CAD model of PC power supply unit.

Manufacturing process of the computer power supply (PSU) (Fig.1) is studied in the numerical example. Manufacturing of the PSU includes five operations. Each operation can be performed by one partner. Five partners are considered for each operation in this case.

Problem of determining the most efficient cooperation among potential partners is considered. Following criteria are assumed: (a) resulting time of manufacturing process and (b) price of manufacturing process. Since shorter manufacturing process means bigger manufacturing costs and vice versa, these criteria are contradictory. During the optimization process optimal partner consortium and optimal compromise between time and price is calculated.

The objective of MO optimization is to find the set of acceptable solutions to choose among them.

To compare candidate solutions to the MO problems, the concept of Pareto dominance is used. This concept assures that the solutions belonged to the Pareto set is not dominated by any other solution that can improve at least one of the objectives without degradation any other objectives [16].

Problem is solved using "classical" multiobjective optimization method where MO problem is transformed into multiple single objective (SO) problems. SO problem is then solved using Monte Carlo computational algorithm relying on repeated random sampling of solutions. Each SO solution that represents single variation of consortium arrangement. According to this, best variation is finally chosen.

The objective to select the optimal combination $X$ of the partners for all operations to minimise the total cost of the project and the overall time of manufacturing process. The following variables are defined:

$\begin{align*}
  x_i &= j \text{ operation } I \text{ is performed by company } j, \\
  j &\in \{1,2,\ldots,m_i\}, \quad i = 1,2,\ldots,n \\
  m_i &\text{- number of companies for operation } i \\
  n &\text{- number of operations} \\
  cost_{i,j} &\text{- cost of operation } i \text{ performed by candidate } j \\
  time_{i,j} &\text{- time of operation } i \text{ performed by candidate } j
\end{align*}$

Then, the problem can be describe as the following model:

$$
\min_X J(X) = \sum_{i=1}^{n} \left[ cost_{i,x_i} + time_{i,x_i} \right]
$$

(1)

If functions $f_{i,x_i} = f(time_{i,x_i})$ are defined for i-th company performing j-th job, then multiobjective optimization problem can be transformed into single objective problem:

$$
\min_X J(X) = \sum_{i=1}^{n} f_{i,x_i}
$$

(2)
3.1 Define the model parameters
Number of partners: 25 (5 partners for each operation), number of operations: 5
Design Variables: Time for each manufacturing operation - $T_o$, Price for each manufacturing operation - $P_o$.
MO problem is transformed into SO problem assuming that the $P_o$ is function of $T_o$. Linear function $P_o=f(T_o)$ is defined for each partner. Function $f$ has decreasing character where price for operation is decreasing with time for operation. Slope $k$ of $f$ function is defined for each partner. Five potential partners for each operation are considered. Every partner is constrained to perform only one operation. Design variable space is constrained by the rule that each $T_o$ value is randomly generated by ±10% deviance of defined average $T_{oa}$ value with normal distribution.

Fig. 2. Illustration of Pareto solution of the bi-objective optimization problem

Fig.2 depicts a Pareto set for a two-objective minimization problem. Potential solutions that optimize manufacturing price $P_o$ and manufacturing time $T_o$ are shown on the graph. Overall manufacturing time and price are normalized to their maximum values. The red line represents Pareto front of the optimization problem. According this Pareto front, the compromise solution can be chosen. In considered example best compromised solution is obtained for the set of following partners which are responsible for operations:
[4, 5, 2, 5, 2]
Optimal overall time is 292 s -> optimal comprise between time and price.
Maximum time is 462 s -> cheapest and slowest manufacturing process.
Minimum time is 247 s -> most expensive and fastest manufacturing process.
All numerical calculations have been performed in the MATLAB® environment.

4. CONCLUSION
In this paper, multi-objective optimization method for the partner selection in DMS is presented. An illustrative example of partner selection process for manufacturing of computer power supply unit is discussed. Robustness of Monte Carlo Method has shown a effective approach for solution of constrained multi objective problem. Based on the results of optimization process, the optimal variation of the partner consortium, overall manufacturing time and overall manufacturing costs have been selected. During the optimization process the times and costs related to logistics haven't been considered. Given the fact that logistics may largely affect the time and cost of DMS production, it is very important to take it into account in the further research.

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7. REFERENCES


