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DESIGN OF OPTIMAL CONSORTIUM OF PARTNERS IN DISTRIBUTED MANUFACTURING SYSTEMS

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Abstract: New industrial designs have been appeared on the market in recent years as response to rapid changing of socio-economic challenges. As a result of globalization and rapid development of ICT the cooperation of companies based on mutual coordination and on-line communications obtains high strategic importance. The growing interaction with external partners has resulted in the removal of existing boundaries between organizations, leading to the emergence of new, alternative ways of cooperation so-called Distributed Manufacturing Systems (DMS). Proposed paper gives a view on a development of new methodology of searching and selecting of partners in collaborative networked organizations.

1. INTRODUCTION

Currently, globalization and the continued development of information and communication technologies (ICT) production enters a new era. This era is characterized by continuous changes in products and customer orientation, time to market is significantly reduced.

In order to succeed in today's turbulent market environment manufacturers have to made considerable efforts to achieve agility. They have to also ensure lower costs of products and faster time to market. However, for most of them, these requirements are too difficult to fulfil within their own resources. It is clear that the development and manufacture of products accounts for an increasing number of manufacturers, suppliers, subcontractors, distributors or customers resulting in an increasing need to create joint partnerships.

In recent years, several new designs appeared on the market in response to rapid changing of socio-economic challenges. Scattering of production functions, the development of ICT and customer orientation approach has become one of the major factors resulting in companies’ cooperation based on mutual coordination and on-line communications gaining high strategic importance. The growing interaction with external partners has resulted in the removal of existing boundaries between organizations, leading to the emergence of new, alternative ways of cooperation such as Distributed Manufacturing Systems (DMS). The Paradigm of DMS is conditioned not only by the development of the market environment but mainly by the need to improve competitiveness on market. DMS concept has evolved from the concepts as a virtual company, virtual company or virtual corporation. Unlike traditional businesses it is characterized by greater flexibility and ability to quick respond to market changes.

Although the literature and Internet sources offer several types of alternative names, the concept of DMS is widely accepted not only in industry but also academia. It is a grouping of geographically distant and systemically integrated companies involved in the formation of a joint product of the functional requirements of the market. It follows that the provision of key skills is necessary but not sufficient condition for the success of DMS. It is obvious that choosing the right partners is essential to the successful establishment and operation of the DMS. Selection of partners, as well as their search in the DMS, despite considerable attention to this issue is constantly widely studied.

This paper addresses the task of finding and selecting an optimal combination of partner companies to create appropriate DMS. Specifically, selection of partners from the virtual network (VBE) source for the DMS configuration support through a variety of multi-criterial optimization methods is described.

The rest of the article is organized as follows. The second chapter presented an overview of the current state of the art of searching and selecting partners to business level. The third chapter describes a comprehensive methodology for the search and selection of partners, including restrictive conditions, the evaluation function and various optimization methods used for selecting the optimal consortium partners. In the fourth chapter an illustrative example is presented to show the application of the proposed methods. The last chapter presents the achievements and areas for further research.

2. THEORETICAL BACKGROUNDS

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 numbers of researchers are addressing the problem of selection of partners used quantitative analytical methods [14], 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. GENERAL DESCRIPTION OF THE PROPOSED SOLUTION

Suppose an attractive business opportunity for specific products has been detected but the company that detected a business opportunity is not able to answer on its own production capacity, know-how, financial and technological resources. For this reason, company decides to divide the project into several sub-projects (sub-projects) to create a network of priority activities (precedence activity network). An example is a project consisting of nine sub-projects, illustrated by precedence activity network in Figure 1 below. The company, which saw a business opportunity, will act as project coordinator. Due to limited resources, the project coordinator decides to create a DMS. In order to achieve the success of the project for tender / selection process to find an optimal combination of partner companies involved in the cooperation of selected sub-projects. Estimated date of completion of the project D = 24 days.

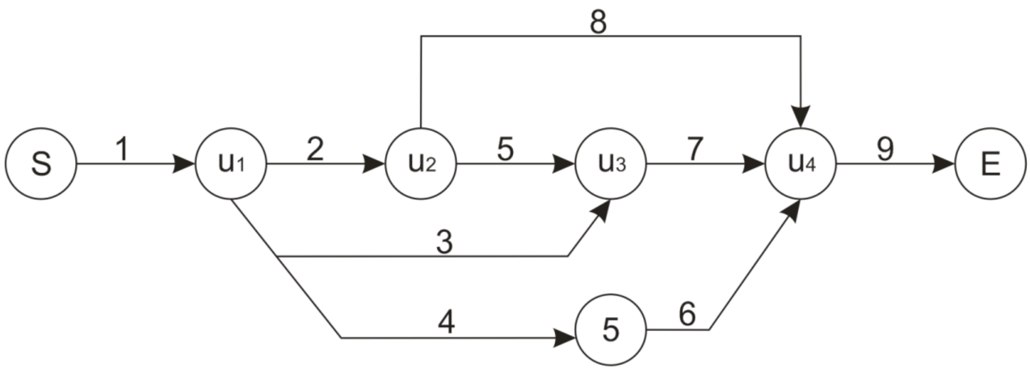

Figure 1. Project described by a precedence activity network

For each of the sub-projects from 3 to 7 business candidates were enrolled, from which the coordinator selects optimal consortium with regard to a specific business opportunity. This study considers the selection of one candidate for each sub-project. The main objective is to minimize the total project cost, subject to the due date of the project and subjected to the primacy of individual relationships. When selecting the partners, production costs, production time and time of completion of the project are taken into account. The list of candidates is described in Table 1.

Table 1. List of candidates for all sub-projects

Job No.	Candidate Code	Bid Cost	Proc. Time
1	A1	11	4
	A2	13	3
	A3	14	5
2	B1	14	2
	B2	10	3
	B3	15	1
	B4	8	4
	B5	9,5	3
	B6	7	5
3	C1	150	5
	C2	90	11
	C3	110	9
	C4	130	8
4	D1	14	5
	D2	16	4

Job No.	Candidate Code	Bid Cost	Proc. Time
4	D3	12	7
	D4	10	8
	D5	12	9
5	E1	25	12
	E2	20	13
	E3	27	11
	E4	29	10
	E5	20	14
	E6	30	10
	E7	21	13
6	F1	70	11
	F2	66	14
	F3	68	12
	F4	84	9
7	G1	22	4

Job No.	Candidate Code	Bid Cost	Proc. Time
7	G2	19	4
	G3	25	3
	G4	17	5
	G5	21	4
	G6	18	5
	G7	25,5	6
8	H1	43	12
	H2	38	13
	H3	50	11
	H4	31	14
9	I1	10	5
	I2	14	3
	I3	12	4
	I4	11	5

3.1 MODEL FORMULATION

In general, we assume that the project consists of *n* sub-projects. Network graph, has been designed to represent the precedence relations between sub-projects. If the sub-project *i* may only begin after completion of the sub-project *k* i.e. sub-projects *k* precedence to sub-project *i*, it makes sub-project pair which can be specified as $(k,i) \in H$. Where *H* is the set of all pairs of sub-project. The final sub-project is called the *n* sub-project, with the result that the completion time of the last sub-project c_n is also the time of completion of the project. To facilitate understanding of the issue of partner selection variables used are described in Table 2.

Based on the precedence of sub-projects, starting time s_{ix_i} and completion time c_{ix_i} are defined as

$$c_{ix_i} = s_{ix_i} + p_{ix_i}$$

$$s_i = \begin{cases} max\{c_k, \forall\,(k,i) \in H\}, & if\ there\ exists\ (k,i) \in H \\ 1, & if\ there\ doesn't\ exist\ (k,i) \in H. \end{cases}$$

$$x = \{x_1, x_2, \dots, x_m\},\ \ x_i \in \{1,2,\dots,n_i\},\ \ i = 1,2,\dots,m. \quad (3.1)$$

For partner selection problem equation (1) will be used to complete the optimal allocation of partners for each sub-project when considering sub-project precedence and limitations of the due date of the project.

Table 2. Notation used in model formulations

Used notation	Meaning of notation
D	Due date of project
S	Array of sub-projects partners
S‘	Array of sub-projects partners after elimination
S_i	i-th subproject
n	Number of sub-projects included in project
m_i	Number of candidates / partners in the sub-project

b_{ij}	Price of j-th partner in the i-th sub-project
p_{ixj}	Process time j-th partner in the i-th sub-project
s_{ixi}	Beginning time of candidate i for sub-project i
c_{ixi}	Completion time of candidate i for sub-project i
c_n	Completion time of the project, i.e., completion time of final sub-project
c_{min}	Minimum duration of the project
c_{max}	Maximum duration of the project
b_{fin}	The final price
b_{max}	Maximum cost of the project
A, B_1, B_2	Auxiliary fields
x	Realization of a random selection of partners for individual sub-projects
x_i	i-th a partner in the implementation of the subproject selection x
x_{ij}	j-th partner i-th sub-project
$\{x_{ij}\}$	Making a choice with elements xij
H	Set of all connected sub-project pairs
(i,k)	Connected sub-project pair
HGA	Hybrid genetic algorithm
DSM	Direct search method

Solution steps:

Step 1) Elimination of unsuitable partners in terms of price, or procedural time
Step 2) The design objective functions for time and cost of the project according to the network graph,
Step 3) Find the exact solutions directly by scanning the entire array of solutions
Step 4) Find the solution using different optimization methods (HGA, DSM).

Outputs:

input n, D, S

Elimination:

1. Create an auxiliary field (B1, B2), which will be used to store intermediate results obtained at each sorting
2. In the program MATHEMATICA using build in features we will sort sub-projects in the field firstly by the prices and exclude all partners at the same time process requiring a higher price. Save result in an array B1.
3. Sort by B1 field of process time and avoid all the partners at the same prices, require a longer process time.
4. Excludes all partners in the sub-project require the longest time procedural highest price.

Create empty B1, B2

```
begin
do i=1, n
    B1= SortBy[S, bi,j]
    if  bij = bi,j+1   pixj < pi,xj+1 , eliminate xij+1 in B1

    B2= SortBy[B1,pix,j]
    if  bij < bi,j+1   pixj = pi,xj+1, eliminate xij+1 in B2
    while (if  bij < bi,j+1   pixj < pi+1,xj)
```

```
            eliminate xi+1j+1 in B2
        end
    end do
    B2 = S‘
    output (S‘)
    end
```

The evaluation function of time

The evaluation function was created according to the attached flowchart.It calculates the total process time with regard to the following individual projects (eg, sub-project 2 can only start after the first sub-project) In the event that several sub-projects running simultaneously and after their completion another sub-project starts, we choose the objective function of process time of longest subproject.

$$c_n(x) = p_{1x_i} + max[(max[(p_{2x_i} + p_{5x_i}), p_{3x_i}] + p_{7x_i}), (p_{4x_i} + p_{6x_i}), (p_{2x_i} + p_{8x_i})] + p_{9x_i} \quad (3.2)$$

We find the minimum and maximum duration of the project cmin and cmax substituting the minimum and maximum times of the individual sub-projects to function cn. If it is satisfied that the minimum time the project is less than or equal to the date of completion of the project, there is at least one successful implementation.

if cmin≤D then „project is realized“
else „project is not realized due to time of realization“

The evaluation function of price

We are looking for low prices functions meeting the above conditions. If in addition the condition that the maximum process time duration of the project is shorter than the deadline for completing the project, minimal implementation costs calculated as the sum of the minimum cost of the individual sub-projects. Thus eliminating the field S’ sorted by price it will be the first partners in the single sub-projects.

if cmax< D then choose {xij| min bij }

If the condition is not satisfied minimum of function is calculated according to term 2 in [7].

$$\min_x Z(x) = \sum_{i=1}^{n} b_{ix_i} + r \sum_{t=1}^{c_n(x)} \left[\alpha \sum_{s_i(x)\le t} b_{ix_i} + (1-\alpha) \sum_{c_i(x)\le t} b_{ix_i} - \sum_{\tau=1}^{t} e(\tau) \right]^+ + \beta [c_n(x) - D]^+ \quad (3.3)$$

Because our project is realized in the period of time, which is not expected to need to finance its cover through bank loans, it reducing the function of the form:

$$\min_x Z(x) = \sum_{i=1}^{n} b_{ix_i} + \beta [c_n(x) - D]^+ \quad (3.4)$$

In which added a penalty cost for tardiness, in case of exceeding the due date.

4 ILLUSTRATIVE EXAMPLES

This section will describe the different optimization methods used to find the optimal choice and the consortium partners to create a DMS.

4.1 DIRECT SEARCH METHOD WHOLE SPACE FOR PARTNER SELECTION PROBLEM

Create an auxiliary field A, in which we store all feasibility satisfying the condition that the total process time of the selected implementation is shorter than or equal to due date cn ({xij}) D. Auxiliary array R is formed by the ordered triplet {implementation {xij, cost of implementation, process execution time}.

In MATHEMATICA by build in feature we choose the all those implementation, where the cost of the project reaches a minimum.

```
create A
begin
   do i=1,n
      do j=1,mi
          If[cn ({xij})  D, AppendTo[A, {xij}]
     end do
   end do
   R={A,Z(A),cn(A)}
   find {Ri| Z(Ai)=min Z(A)}
output ({Ri})
end
```

For the specific parameters of the selected project (completion date where D = 24 and k = number of sub-project 9) is:

The size of the solutions before elimination – 1128960,
The size of the solution after elimination – 92160
Cheapest solution: process time= 32 price= 262
Most expensive solution: process time = 20 price= 386

The result of the direct method:

Using the direct method of searching the following optimal solution has been found: A2, B3, C2, D3, E2, F1, G2, H4, I2 with a total cost of the product 284 million and completion time of 24 days. In this case, were found suitable combination of 3 different partners at the same price and time of completion of the project (due date).

Partners combination:

1. A2, B3, C2, D3, E3, F1, G2, H4, I2
2. A2, B3, C2, D1, E2, F3, G2, H4, I2
3. A2, B3, C2, D2, E2, F2, G2, H4, I2

Calculating time: 7,86 s
For non-reduced area of solution 1 128 960 calculating time was 56,3165 s.

Table 3. List of candidates for direct search method

Job No.	Candidate Code	Cost	Proc. time	Begg. Time	Compl. Time
1	A2	13	3	0	3
2	B3	15	1	3	4
3	C2	90	11	3	14
4	D3	12	7	3	10
5	E2	20	13	4	17
6	F1	70	11	10	21
7	G2	19	4	17	21
8	H4	31	14	4	18
9	I2	14	3	21	24

4.2 HYBRID GENETIC ALGORITHM FOR PARTNER SELECTION PROBLEM

To address the issue of partner selection using a genetic algorithm we use the original array S:

1. Create a population of random realizations x of the array element S
2. Select genes to be crossing
3. Sets the shift of genes crossing along the realization of x, evaluate population by the objective function subjected to the condition $c_n(x) \leq D$. Save the realization of a minimum value into the array.
4. Specify the number of generations

cycle
  cycle
    we will cross for the number of genes between adjacent realizations
    we evaluate the new population according to objective function
    sorts a new population according to the selected parameter
    Save the best result in an array   end of cycle
  Switch to next n-th genes
End of cycle
From the results array we chose the best result

Results:

Size of population: 1000
Number of generation: 100
Number of chromosomes to exchange: 1
Shift after 10 generations
Optimal solution found: A2, B3, C2, D3, E3, F1, G2, H4, I2
Overall costs= 284   Overall processing time= 24

Found solution coincides with the first variant of the method of direct searching.
Calculation time: 11.406 s

4. CONCLUSIONS

Despite considerable attention to the issue of search and selection of partners, a number of areas not receiving enough attention. In this introductory article two multi-criteria optimization methods for selecting partners in the DMS are presented. Direct methods of searching the solution space and hybrid genetic algorithm were used to find the optimal solution. Direct method has the advantage that it always finds an optimal solution, unlike the Hybrid genetic algorithms, which accuracy depends on several factors such as restrictive conditions, calibration of optimization method, the evaluation function, the type of optimization problem, the number of iterations and the size of the initial population. On the other hand, the advantages of HGA are relatively short computational times, as opposed to direct methods of searching, where the length of the calculation increases exponentially with the complexity of calculation and the size of the search area. These optimization methods are potentially applicable to a wide portfolio of problems dealing with issues of looking for the best solution selected from a large set of potential solutions with regard to the multiple constraints and selection criteria.

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