ISSN 1330-3651
UDC/UDK 658.5.018.2:004.7

OPTIMIZATION OF THE SELECTION OF COMPETENCE CELLS IN REGIONAL PRODUCTION NETWORK

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Preliminary notes

The ongoing world economic crisis has shown that being a successful enterprise in normal economic conditions is not a guarantee of sustainability. So the crisis has led to bankruptcy of many successful enterprises, especially large-sized enterprises. This brought into question the future of large-sized enterprises, but at the same time raised the question whether there is an alternative to large-sized enterprises. Of course, there is an alternative in networking of small and medium-sized enterprises and their optimal selection in the creation of new virtual enterprises. This paper deals with the problem of the selection of cooperators for the new production process. It is assumed that enterprises can be mutually compared and ranked, and that makes optimization possible, using Ant Colony Optimization (ACO) algorithm.

Keywords: *competence cell, virtual enterprise, ACO*

Optimizacija odabira kompetencijskih stanica u regionalnoj proizvodnoj mreži

Prethodno priopćenje

Današnja svjetska gospodarska kriza pokazala je da uspješno poslovanje poduzeća u normalnim ekonomskim uvjetima nije garancija održivosti, tako da je kriza odvela u stečaj mnoga poslovno uspješna poduzeća, a pogotovo velika poduzeća. Ovo je dovelo u pitanje budućnost velikih poduzeća, no u isto vrijeme i otvorilo pitanje postoji li alternativa velikim poduzećima. Alternativa, dakako, postoji u umrežavanju malih i srednjih poduzeća i njihovom optimalnom odabiru u stvaranju novih virtualnih poduzeća. Ovaj se rad bavi baš navedenim problemom odabira kooperanata (kompetencijskih stanica) za određeni novonastali proizvodni proces. Pretpostavlja se da je poduzeća moguće međusobno usporediti i rangirati, što otvara prostor za optimiranje pomoću algoritma Ant Colony Optimization (ACO).

Ključne riječi: *kompetencijska stanica, virtualno poduzeće, ACO*

1 Introduction

The process of globalization, more liberal trade between countries around the world and the economic crisis in 2008 showed 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 production-oriented enterprises. Today's production-oriented enterprises need to have a high degree of specialization in different narrow fields of work, and, at the same time, a flexible production system that will "listen" and adapt to the needs of customers (a very specific ones, and a wide range ones). This creates a new vision of a modern enterprise which needs to unite the somewhat contradictory requirements (specialization vs. flexibility). It would therefore be wrong to search for solutions within a traditional production system of a large-sized enterprise (LE - Large-sized Enterprise), but the solution lies in the networking of small production systems of small and medium-sized enterprises (SME - Small and Medium-sized Enterprise).

SMEs, which primarily apply new technologies with ease, were recognized by the European Union as the key factors of transformation of the European "knowledge economy". According to the EU, the enterprise is classified as SME if: it is independent, has 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 % (Fig. 1).

A particular potential are micro enterprises that have the productivity level of 62 % which is up to 25 % less than the productivity of SMEs. This lack of productivity is primarily classified as unused capacity, or lack of work, because in these micro enterprises insufficient marketing

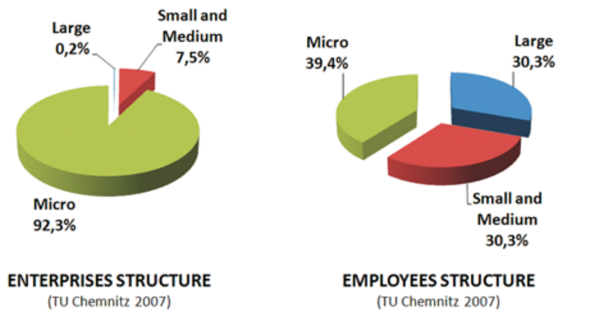

Figure 1 Structure of industrial enterprises in the EU

activities are present. When it comes to the Republic of Croatia, the structure of industrial enterprises is similar (Fig. 2).

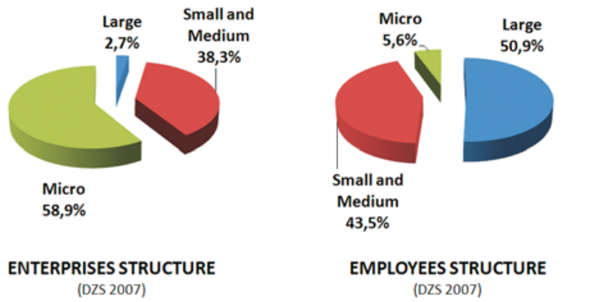

Figure 2 Structure of Industrial Enterprises in the Republic of Croatia

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 % (Tab. 1) and an increase in the number of employees by 22,6 % (Tab. 2). While in the same period the number of LEs remained the

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

	Large	Small and medium	Micro (Very small)
2004	210	2 108	4 133
2007	210	2 942	4 523
Increment	**0,0 %**	**39,6 %**	**9,4 %**

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

	Large	Small and medium	Micro (Very small)
2004	155 181	105 874	14 927
2007	151 867	129 819	16 862
Increment	**-2,1 %**	**22,6 %**	**13,0 %**

same, and their number of employees declined by 2,1 %.

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.

One of the key strategies of development of SMEs is their networking in the regional co-operation network. Currently the most famous concept is the "Competence-Cell-based Network" developed by Müller et al. at the Technischen Universität Chemnitz [1, 2]. 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 it has ex-Eastern Germany.

2 Competence-cell-based network

This concept implies the networking of small and medium-sized enterprises (SMEs) in the non-hierarchical regional production networks. Such a network is called competence-cell-based network. 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. Such a network contains elements of a holistic system [3], 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 competence-cell-based network. Which means, all enterprises in the network, in addition to already existing co-operation, are willing and able to develop new co-operations on new projects - new product development [4] (Fig. 3).

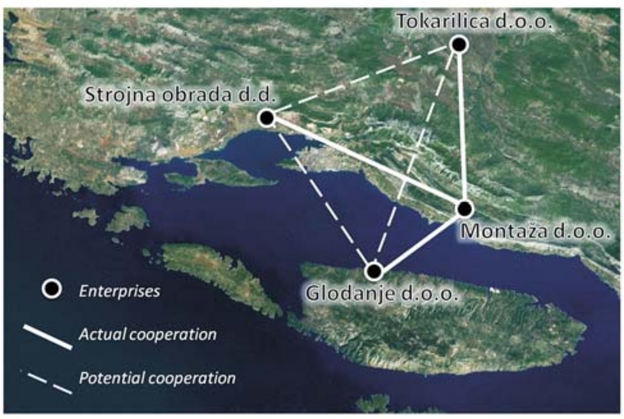

Figure 3 Example of simple competence-cell-based network

Müller et al. [2] identify several types of competence-cells which represent essential elements of the value adding process: marketing, product development, production planning, production, assembly, quality and service. According to this concept all of the above mentioned competence cells communicate with each other using a special Web portal.

Although Müller et al. distinguish several types of competence-cells; this paper will be limited only to the competence-cells for production and assembly. The aim is to choose optimal combination of them in order to set up a new Virtual Enterprise to produce a new product.

3 The problem of the selection of cooperators in the competence-cell-based network

The problem of the selection of cooperators (partners) arises when the production process is parsed to technology processes that need to be done to produce a product. In fact it is very likely that the same technological process can be done by two or more different cells (enterprises) in the network. The question is: which enterprise to choose [5, 6]? Therefore, it is obvious that, before the selection process, enterprises need to be evaluated on the basis of their performance. In this way, enterprises with the highest rating will be selected and they will form a new Virtual Enterprise.

However, the evaluation of enterprise performance is a complex problem, therefore it will not be analyzed in this paper, and the enterprises ratings will be predetermined. Further, the following figure (Fig. 4) shows a simple problem, i.e. production process, and its solution.

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 process is presented by cells that can perform it. The network is formed by respecting the order of the production process of product or intermediate product.

According to the figure, it is clear that the enterprise with a higher grade is selected to perform a production process. And it is an optimal solution of this problem. But in reality very few production processes are so simple like this one. The majority of the production processes results in a product that is composed of several parts (intermediate products), and the technological processes related to each part can be processed parallel. So this represents complex (parallel) production process.

To enable the display of a complex (parallel) production process in this way, it is necessary to introduce the notion of "branching". Branching in the network graph leads to a solution resulting from the beginning (order) to completion (delivery) that in certain places is divided into multiple paths, and then again connected in one path. In this way the branches are parallel activities in the production process, in which each branch results in the intermediate one, which is ultimately all of us assembled in the final product (Fig. 5).

As it can be seen from the figure, the solution to this problem is not presented by only one way from beginning to end, but the way is in a particular place divided into two ways, and then again merged into one. Therefore, this kind of problem is different from classical network problems, such as for example the problem of optimal (shortest or fastest) way.

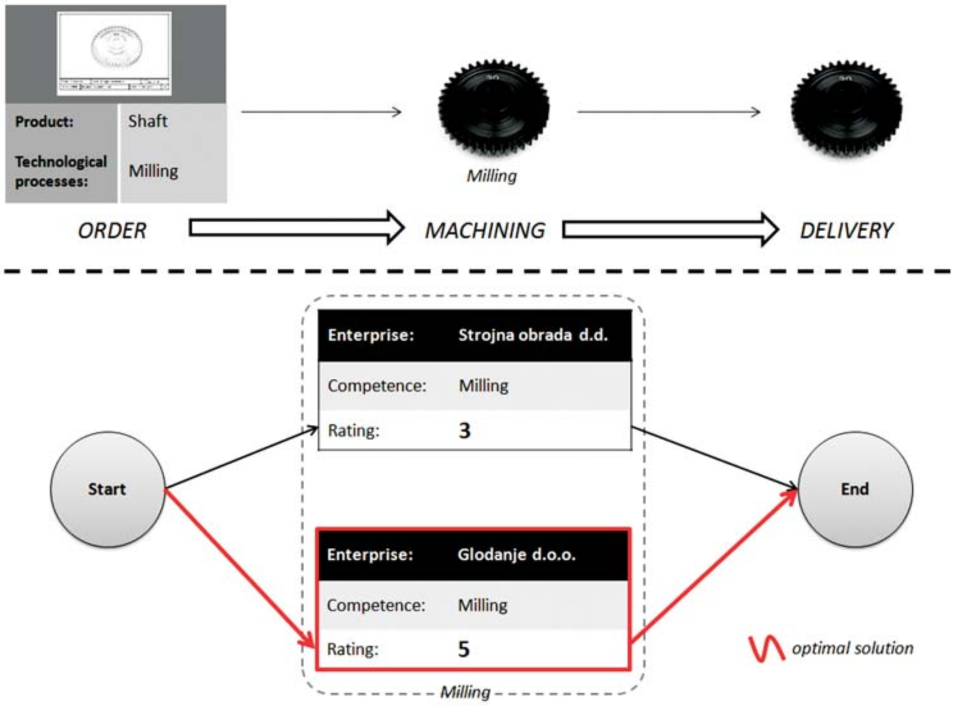

Figure 4 Example of solution of the problem with simple production process

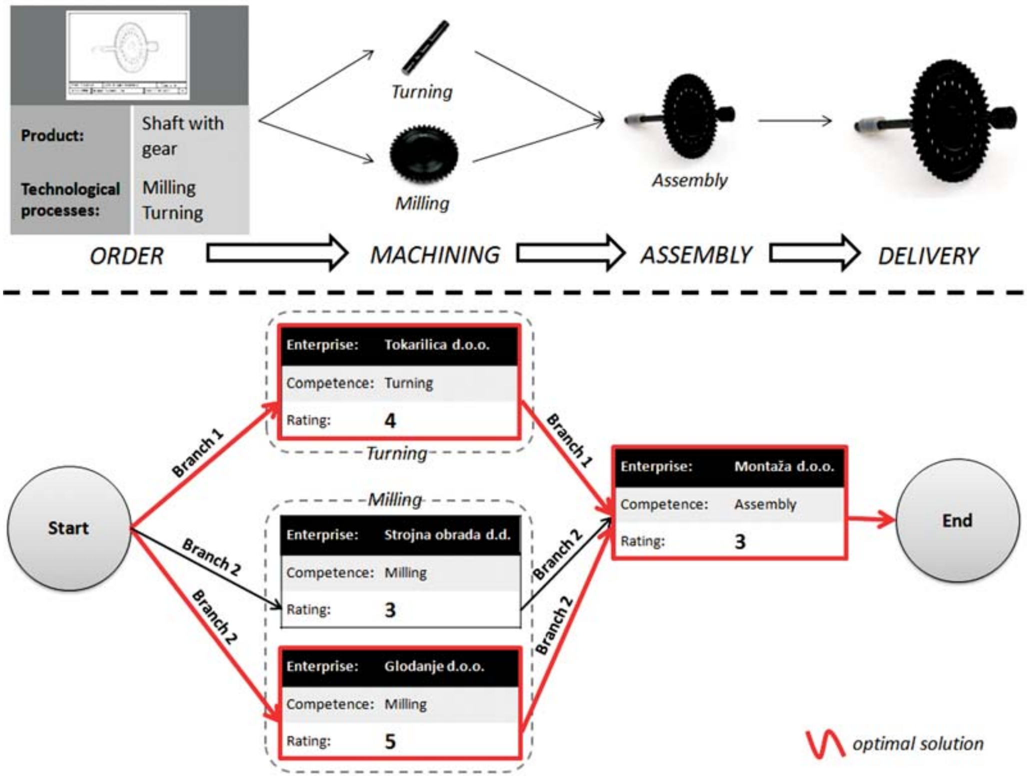

Figure 5 Example of solution of the problem with complex (parallel) production process

3.1 Modeling the problem of the selection of cooperators

In reality this problem is even more complex, because there are different parameters that influence the selection process, and the most relevant are: cells rating, the distances between cells, the capacities of cells and the time needed to fulfill work.

Now, a simple example of a competence-cell based network with 3 cells will be used to analyze the problem and its solution.

The parameters that affect rating of a cell are: distances between cells (Tab. 3) and cells rating (Tab. 4).

Table 3 Mutual distances between cells - L_{ij}

	E1	E2	E3
E1	0	17	11
E2	17	0	7
E3	11	7	0

Table 4 Cells ratings - C_i

E1	5
E2	2
E3	4

Table 5 Cells capacities - K_i

E1	2
E2	2
E3	2

The parameters that represent the constraints are: the capacities of cells (Tab. 5) and the time needed to fulfill work. The parameter "time needed to fulfill work" will be ignored in this paper.

The following problem should be solved (Fig. 6), i.e. select a cell for each technological process. The selected cell will carry out selected part of the production process.

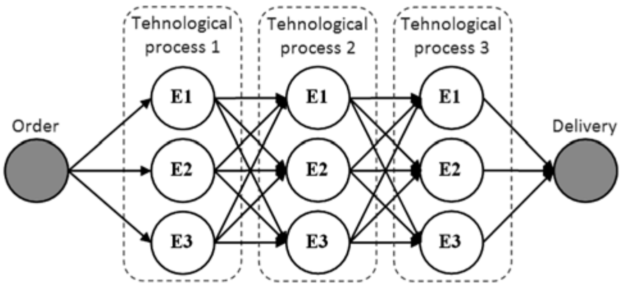

Figure 6 Variants of production process

From the given network graph it can be seen that each cell is competent to perform any of the 3 required processes, so each process has 3 possible variants.

Each solution represents a possible variant of the production process. In this example, because of limited capacities, there are 14 varieties (solutions) of the same production process. To evaluate solutions and to determine which is the most optimal, it is necessary to establish the fitness function f_f. Two parameters affect the value of the fitness function: the sum of distances between the cells involved in the production process and the sum of ratings of cells involved in the production process. However, in order to determine the fitness of certain cell, these parameters should be weighted, and then by summing the weighted values calculate the value that represents fitness of certain cell. It is therefore necessary to introduce a weight for the distance T_L and a weight for rating T_C. In addition, since the fitness value should be maximal and the total distance should be minimal, it is necessary to use a reciprocal value of the distance.

Taking into account the above, the optimal variant of the production process is presented in figure (Fig. 7).

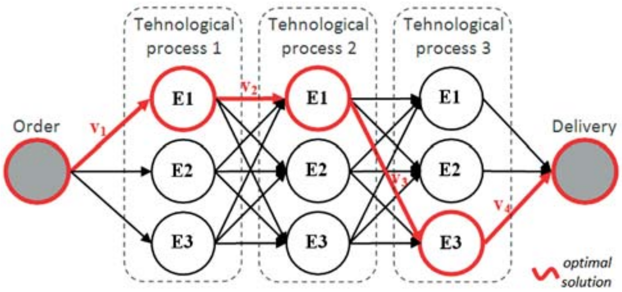

Figure 7 Optimal variant of production process

The solution can be written in the form of a vector:

[E1, E1, E3] → **R** = [1, 1, 3]

If there were no limitation in capacity, the solution would be a vector [**E1**, **E1**, **E1**]. However, due to the limited capacity the entire production process cannot be performed in the same cell.

The expression for calculating the value of fitness function would look like this:

$$f_f = v_1 + v_2 + v_3 + v_4$$

$$f_f = (T_C \cdot C_{R1} + T_L \cdot \frac{1}{L_{R1,0}}) + (T_C \cdot C_{R2} + T_L \cdot \frac{1}{L_{R2,R1}}) +$$

$$+ (T_C \cdot C_{R3} + T_L \cdot \frac{1}{L_{R3,R2}}) + 0.$$

However, this expression has certain problems, so it is not convenient to use. The first problem is the possible division by zero, and the second problem is indifference on staying in the same cell. Namely, since remaining in the same cell means to have a reciprocal value of the distance ($1/L$) equal to zero; it is possible that solutions with high fitness have very high total distance. But it is illogical, because it has already been mentioned that without restrictions in capacity the best solution is to perform everything in the cell **E1**, due to its highest ratings.

To avoid the mentioned problems, it is necessary to set the parameters of the problem a bit different. First of all the distances (in the matrix of distances between cells) that are 0 need to be converted to 0,1; to be able to calculate the reciprocal value. After that, the reciprocal value should be placed in a relative ratio with respect to the maximum value of the matrix. The values of ratings are also placed in a relative ratio with respect to the maximum, while the values of capacities remain the same. Thus, the predefined matrices now look like the following tables (Tab. 6 and Tab. 7).

Table 6 Relative and reciprocal mutual distances between cells - L_{ij}

	E1	**E2**	**E3**
E1	1	0,006	0,009
E2	0,006	1	0,014
E3	0,009	0,014	1

Table 7 Relative cells ratings - C_i

E1	1
E2	0,4
E3	0,8

Now, it is obvious that the algorithm will prefer to stay in the same cell, which means less total distance, and that lowers transportation costs. Putting values in a relative ratio makes it possible to compare two different parameters.

For the solution described above, the expression for calculating the value of fitness function qualities should now look like this:

$$f_f = v_1 + v_2 + v_3 + v_4$$

$$f_f = (T_C \cdot C_{R1} + T_L \cdot L_{R1,0}) + (T_C \cdot C_{R2} + T_L \cdot L_{R2,R1}) +$$

$$+ (T_C \cdot C_{R3} + T_L \cdot L_{R3,R2}) + 0$$

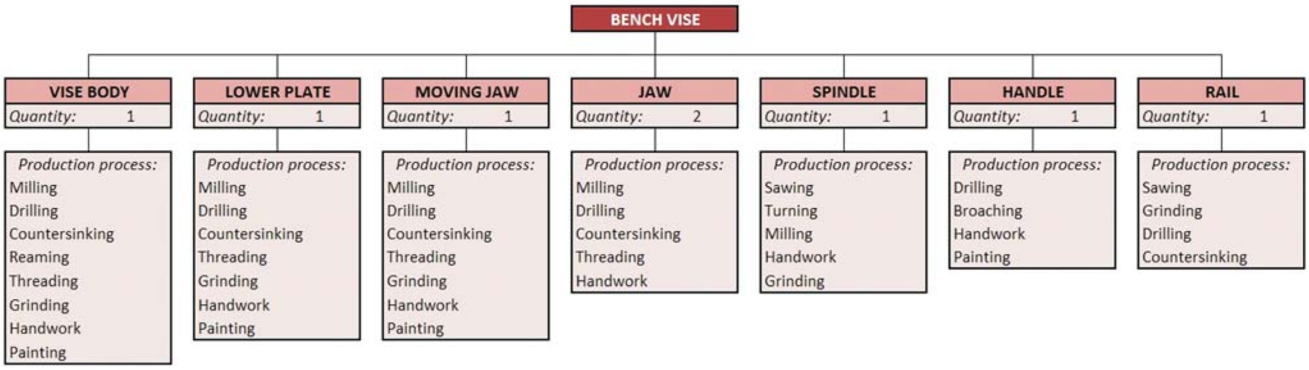

Figure 8 The product whose production process will be solved

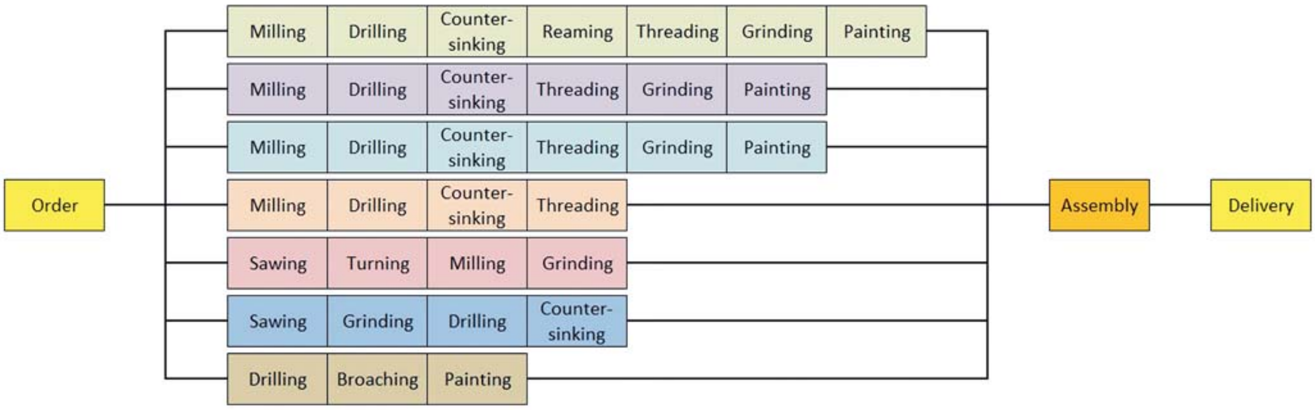

Figure 9 Main production process

$$f_{\mathrm{f}} = (0{,}5\cdot 1 + 0{,}5\cdot 0) + (0{,}5\cdot 1 + 0{,}5\cdot 1) +$$
$$+ (0{,}5\cdot 0{,}8 + 0{,}5\cdot 0{,}009) + 0$$
$$f_{\mathrm{f}} = 2{,}409.$$

In calculation both weighting factors (T_{C} and T_{L}) are given the value of 0,5, i.e. they are equally important.

4 Optimization algorithm of the problem

Since the problem may contain parallel processes (or branches) within the network, it cannot be solved easily by any algorithm for solving network problems. One of the metaheuristic algorithms that are easy to adapt to this kind of problem is "Ant Colony Optimization – ACO".

ACO algorithm is a bit modified [6] in a way that it can solve the problem parallel processes (or problem of branching). It is done by solving each branch separately. If we ignore the capacity constraints and time needed to fulfill work, such an approach is possible, since the branching occurs at the beginning, because it represents intermediate products (parts) which will be assembled in a final product. Therefore, each branch can be solved before solving the complete network, and that will not change the overall solution. The algorithm will be applied and the results analyzed on a network consisting of 12 cells and product consisting of 7 intermediate products (parts). The product is a bench vise, and it consists of parts: vise body, lower plate, moving jaw, jaw, spindle, handle and rail. Each part has its own production process, i.e. the sequence of technological processes needed to be done before the final assembly (Fig. 8).

It is necessary to form the main production process, which contains production processes of each intermediate product, where each intermediate product is one branch of the network (Fig. 9).

To put it simply, to solve this production process for each technological process the enterprise that will fulfill it needs to be selected. The fictional production networks of Split-Dalmatia County with 12 fictitious enterprises (competence-cells) will be used. Each cell can perform various technological processes and they actually determine their competence. Fictional network is shown in the following figure (Fig. 10).

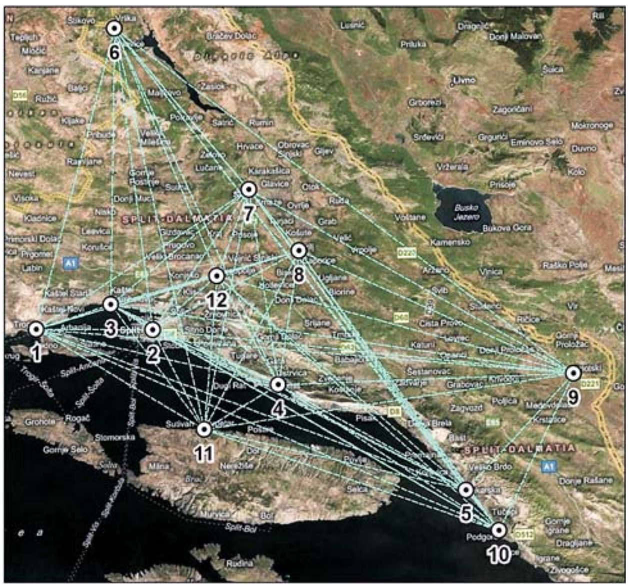

Figure 10 Fictional competence-cell-based network of the Split-Dalmatia County

Table 8 Cells (enterprises) of a network with information about mutual distances, ratings and capacities

ID	Enterprise Location	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	Rating	Capacity
E1	Trogir	0	17	11	36	67	45	37	40	78	73	28	27	5	100
E2	Split	17	0	7	20	51	44	25	24	62	58	16	12	10	100
E3	Kastela	11	7	0	27	58	40	26	29	68	65	23	16	11	100
E4	Omis	36	20	27	0	31	57	29	20	43	39	13	18	9	100
E5	Makarska	67	51	58	31	0	84	54	42	23	8	39	48	3	100
E6	Vrlika	45	44	40	57	84	0	30	42	84	92	60	39	2	100
E7	Sinj	37	25	26	29	54	30	0	12	54	62	35	13	7	100
E8	Trilj	40	24	29	20	42	42	12	0	44	50	29	12	1	100
E9	Imotski	78	62	68	43	23	84	54	44	0	25	54	54	4	100
E10	Podgora	73	58	65	39	8	92	62	50	25	0	45	55	12	100
E11	Supetar	28	16	23	13	39	60	35	29	54	45	0	22	6	100
E12	Dugopolje	27	12	16	18	48	39	13	12	54	55	22	0	8	100

Table 9 Cells (enterprises) of a network with information about their competences

ID	Enterprise Location	Competences
E1	Trogir	Sawing, Milling, Turning, Drilling, Grinding, Assembly
E2	Split	Grinding, Painting, Assembly
E3	Kastela	Painting, Assembly
E4	Omis	Milling, Turning, Assembly
E5	Makarska	Sawing, Grinding, Countersinking, Reaming, Threading, Painting, Assembly
E6	Vrlika	Milling, Turning, Drilling, Grinding, Countersinking, Reaming, Threading, Painting, Assembly
E7	Sinj	Turning, Drilling, Grinding, Assembly
E8	Trilj	Milling, Turning, Drilling, Grinding, Countersinking, Reaming, Threading, Painting, Broaching, Sawing, Assembly
E9	Imotski	Milling, Drilling, Countersinking, Reaming, Threading, Grinding, Assembly
E10	Podgora	Milling, Assembly
E11	Supetar	Sawing, Milling, Turning, Drilling, Grinding, Assembly
E12	Dugopolje	Sawing, Turning, Drilling, Assembly

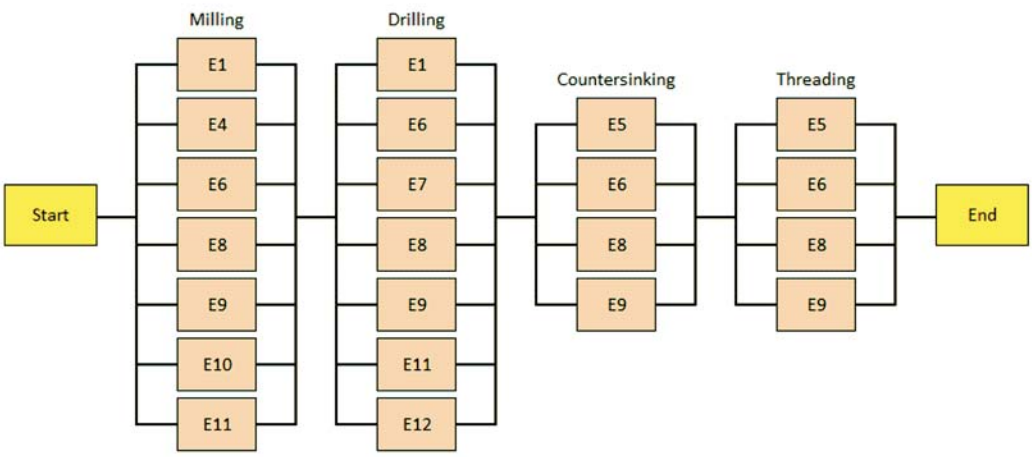

Figure 11 Production process of intermediate product with alternatives for each technological process

All cells of network are mutually connected, and that represents a potential mutual cooperation of cells. All relevant information about the cells is represented in the following tables (Tab. 8 and Tab. 9).

The tables show that different cells have different competences, some very few of them, while some can do all the required technical processes. The assumption is that the smaller enterprises with narrow field of work can be more specialized, technologically advanced and superior. Therefore, these enterprises will probably have a higher rating than the enterprises with wide field of work. To achieve a better variety, the range of ratings is equal to the number of cells, ranging from 1 to 12, and rating actually represents the rank (but inverted). For each intermediate product a network with alternatives for each technological process is developed (Fig. 11). The cells are represented by their "ID".

The figure shows the production process of vise jaws. The same network needs to be created for each intermediate product, but also for the entire product. The algorithm will choose optimal cell for each technical process, trying to optimize the entire production process. The problem will be solved with the help of the software package "MATLAB". Flowchart of the ACO algorithm is presented in the following figure (Fig. 12).

4.1 Solving and analysis of solutions to the problem

As mentioned before, the problem is solved by using a modified ACO algorithm written in MATLAB. Achieved results were satisfying, and now they will be analyzed. It is important to note that cells capacity constraints were ignored, so each cell has infinite capacity. The parameters

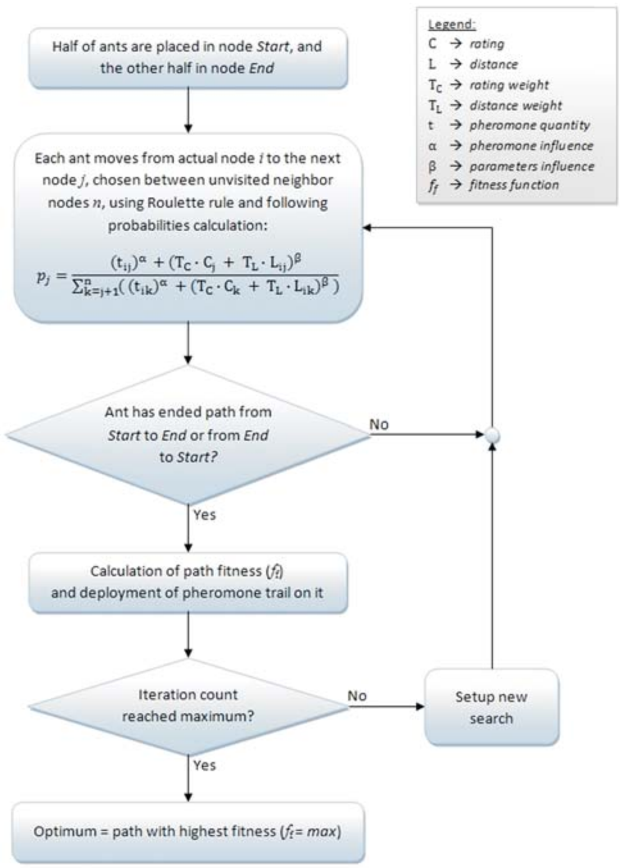

Figure 12 Flowchart of the modified ACO algorithm

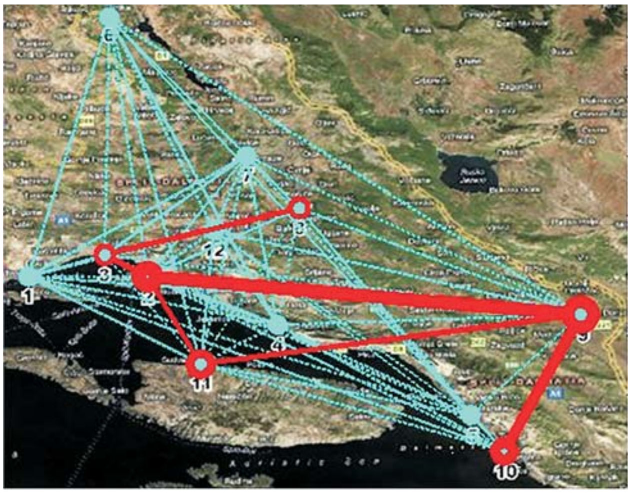

Figure 13 One of the optimal combinations of cells for production of bench vises

"better" than optimal. But, with the currently available resources, these "better" are also unrealizable solutions.

5 Conclusion

This paper proved that it is possible to optimize the selection of cooperators in a regional production network, with the help of the modified ACO algorithm. It also proved that the assignment of various technological processes (of the same production process) to various enterprises achieved higher average rating, which should ultimately lead to greater quality of processes and products. Once

					
Rating weight T_C = 0,2	Distance weight T_L = 0,8	Rating weight T_C = 0,5	Distance weight T_L = 0,5	Rating weight T_C = 0,8	Distance weight T_L = 0,2
Avg. Rating: **2,49** Total Distance: **228 km**		Avg. Rating: **5,34** Total Distance: **404 km**		Avg. Rating: **7,83** Total Distance: **958 km**	

Figure 14 Different optimal solutions for different weighting factors of the parameters

that affect selection were the rating and the distance. The following figure (Fig. 13) shows one of the optimal solutions, which has weighting factors set to T_C = 0,6 and T_L = 0,4.

Solving this example with different weighting factors for parameters revealed 7 different optimal solutions, or 7 different optimal combinations of the production process. The person responsible for the process will decide on one of the solutions, taking into account the quality requirements (which are represented by rating) and the permissible amount of transportation costs (which are represented by total distance). Three different optimal solutions are presented in the following figure (Fig. 14).

Optima can be presented as a curve that represents the Pareto front (Fig. 15). Below the curve are solutions "worse" than optimal, and above the curve are solutions

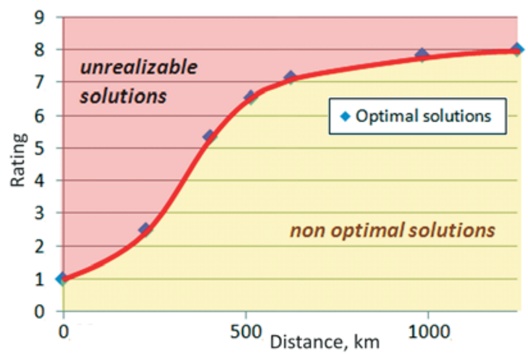

Figure 15 Optimal solutions and the approximated Pareto front

again it has been shown that networking enterprises in regional production networks makes sense and will surely find its application in the near future.

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