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PROJECT ORIENTED PRODUCTION OPTIMIZATION

In this paper the resource – constrained scheduling problem is discussed. The objective function is minimization of makespan under constrained resources and due time. The metaheuristic based on Ant Colony Optimization (ACO) is proposed for multi-project scheduling. The elaborated method, algorithm and example illustrating ACO application for the multi-project scheduling problem is presented.

1. INTRODUCTION

A trend of individualizing products is particularly noticeable in small and medium-sized enterprises (SMEs). Most companies in this sector are geared both to produce variable products and (in many cases) to produce a unique type of product. The reason of such situation is that customers change goods, due to changes in fashion, lifestyle, etc., even if products have not lost their relevance. Changes in consumer attitudes led to the unique production process. Because of that production orders are always treated as a new one, and in many cases are managed in accordance with the principles of the project management [1]. Therefore, in recent years growing interest in the form of management in the project oriented production management is observed [2].

This paper discusses the multiproject management problem. Ant Colony Optimization is proposed for scheduling in that resource – constrained environment.

2. PROJECT ORIENTED ACTIVITIES

A project is defined as a set of activities needed to create a unique product or services. According to Brilman [3] over 25% of all professional activity can be managed as a project, therefore project management is a branch of organizing and managing resources.

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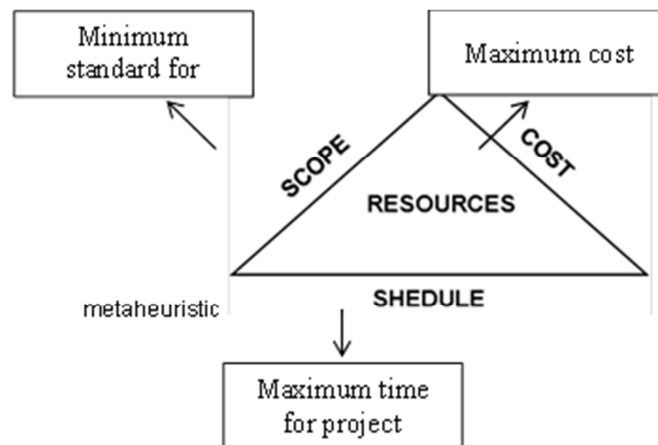


Fig. 1. Three necessary conditions [4]

For the project satisfaction three necessary conditions: the scope, the schedule and the budget, are required (Fig. 1). The scope sets a minimum standard for the project result. The budget sets a maximum cost. The schedule sets the maximum time for the project. This three conditions are interdependent (e.g. the longer a project takes, the more it costs; the longer project takes the more opportunities exist to change the scope) [4].

A project consists of activities performed according to some precedence constraints.

RCPSP and RCMPSP involve assigning jobs to a constrained resources in order to meet predefined objectives. RCPSP is the problem of determining starting time of each activity of a project satisfying precedence and resource constraints in order to minimize the total project duration. The precedence constraints impose that an activity can start after the completion of all its predecessors. The execution of an activity cannot be interrupted and requires, for each period of its duration, constant amounts of a subset of renewable resources. Many different objectives are taken into account and these depend on the goals of the decision maker. The most common objective is to find the minimum makespan (i.e. minimization of project duration). In the RCPSP, each activity has a single execution mode: both the activity duration and its requirements for a set of resources are assumed to be fixed, and only one execution mode is available for any activity [5],[6].

RCMPSP is a generalization of the RCPSP. In a RCMPSP environment a company has several concurrent projects, each consist of a set of activities (each activity has associated attributes) and for each project activity has a corresponding precedence constraints. Projects depend on a common set of resources and are therefore related by resource constraints.

Management of the multiproject environment is management of concurrent projects, among which there are no precedence constraints, but they may utilize the same (shared) resources according to excluded-like mode.

The dependencies that connect different projects with others may be technological, knowledge-oriented, product-oriented or interlinked by the deliveries made to the customer.

At the same time, there may be projects that are independent regarding the attributes mentioned above, but which share some resources (such as people, machines) with other projects.

Project management approach can be shown on the example of a packaging.

The packaging industry consolidating its position has become more competitive, and by adjusting to the changing trends has also become more flexible.

The packaging should be regarded as a specific device, characterized by strictly assigned features. The essence of packaging depends on its function to execute, depending on whether it is intended to protect the product, facilitate the transportation, storage, or to stimulate the imagination of potential customers, for which the product is dedicated to.

Packaging is created in the last stage of the design of the product itself, when parameters necessary for its design and production (weight and dimensions) are known. Therefore, the time remaining for the package design in the context of a number of issues and objectives, which at this point must be taken into account is extremely short. Design and manufacturing of packaging in any case cannot be the cause of the product market entry delay.

For this reason, while preparing the packaging design, the criterion governing the scheduling of design and implementation works is to minimize makespan C_{max} . One product is often related to higher number of packages, as it is a container for a single product (individual), a collective packaging, and often one additional associated with the way of transportation. These projects and their first series should be created at the same time.

3. MULTIPROJECT SCHEDULING – CRITICAL REVIEW

Most of the heuristics methods used for solving resource-constrained project scheduling problems either belong to the class of priority rule based methods or to the class of metaheuristic based approaches [7]. While exact solution methods are able to solve smaller problems, heuristic and metaheuristic approaches are needed for larger problem instances. Many metaheuristic methods, such as genetic algorithms (GA), simulated annealing (SA), tabu search (TS), and ant colonies (AC), have been applied to solve the RCPSP. Metaheuristics based on GA are the most common, e.g. Lee and Kim in [8], Alcaraz and Maroto in [9]. Simulated annealing algorithms in resource constrained project scheduling problem are presented by Boctor in [10], Bouleimen and Lecocq in [11]. Tabu search based on metaheuristics are proposed by e.g. Pinson et al. in [12]. Merkle et al. in [13] proposed an ant colony approach to the RCPSP.

Pritsker et al. in [14] proposed a zero – one programming approach for the multi – project scheduling. Most of the heuristic method used for solving RCMPSP belong to the class of priority rule based methods. Several approaches of this class have been proposed in the literature, e.g. Tsubakitani and Deckro in [15], Lawrence and Morton in [16], Wiley et al. in [17], Lova et al. in [18].

Heuristic methods typically require less time and/or space than exact methods. The heuristics specify how to make a decision given a particular situation (heuristics are rules for deciding which action to take). Heuristics may be deterministic - they end up with the same result every time - or they may be stochastic – each time they are run they may produce a different result. Scheduling heuristics operate on a set of tasks and determine

when each task should be executed. If a task may be executed in more than one execution mode or on any one of a set of resources, the heuristic must also determine which resources and/or execution mode to use [5],[6].

The research literature for the RCPSP is quite large. A great number of exact methods to solve the RCPSP are proposed in the literature. The exact methods applied to the RCPSP can be classified into three categories: dynamic programming, zero-one programming and implicit enumeration with branch and bound. Blazewicz et al. in [19] showed that the RCPSP as a generalization of the classical job shop scheduling problem belongs to the class of NP-hard optimization problems. Therefore, the use of heuristic solution procedures when solving large problem is well - founded.

4. PROBLEM FORMULATION

Given is a system dedicated for individual demands execution. It can be production firm. Two groups of constraints are defined. From one side a firm possibility is limited by resource capacity and availability in a considered time interval. From the other side given is a set of task for concurrent realization in this system, in restricted due date. From both client and producer point of view both groups of constraints should be satisfied, it means that the set of tasks must be executed in this system as soon as possible without exceeding any constraints. In this paper the problem of makespan minimization is presented.

It was assumed:

In the considered case, we focus on a multiproject environment:

- the set of project is given,
- portfolio of orders is determined, the closing date will be appointed,
- resources are renewable.

For each one project is assumed:

- a set of project activities is given,
- each step of the project is characterized by resource requirements,
- a set of constrained resources is given,
- actions precedence constraints are known,
- activities are non-preemptive,
- time function is defined, the start and finish time for operations are not determined,
- between project activities occurs a relationship of an end - start type,
- a partial occupancy of resources is not provided, the resource can be either occupied or unoccupied. In addition, it is assumed that the realization of actions on the resource is executed directly one after another.

It is assumed, moreover, that each activity is performed on a single resource, and that the initial and final activities are a conventional activities that have a zero resource requirements and do not affect the course of the project.

Milestones, as points which do not allow to minimize the length of the makespan (despite the early completion of the work within the milestone, further activities should wait until the established date stone) have been rejected.

The main objective of scheduling under resource constraints is to minimize the makespan - Cmax.

It is assumed that the availability of resources determines the acceptance of a new project for concurrent execution. At the time of notification of the project to carry only known resource requirements for the activities of the project. At the time of submission of a project to implement resource requirements for the activities of the project are known. In each time unit t use of resources by the activities does not exceed the available level. Availability of resources is described by matrix R . Resource requirements for the activities of the project are stored in the matrix Z :

Matrix R

r_k	r_1	r_2	...	r_k
t	a_1^t	a_2^t	...	a_k^t
1	a_1^1	a_2^1	...	a_k^1
2	a_1^2	a_2^2	...	a_k^2
...
t	a_1^t	a_2^t	...	a_k^t

Matrix Z

r_k	r_1	r_2	...	r_k
j	z_1^j	z_2^j	...	z_k^j
1	z_1^1	z_2^1	...	z_k^1
2	z_1^2	z_2^2	...	z_k^2
...
t	z_1^t	z_2^t	...	z_k^t

where:

- a_k^t availability of k -th resources at unit time t ,
- z_k^t k -th resource requirements for activity j .

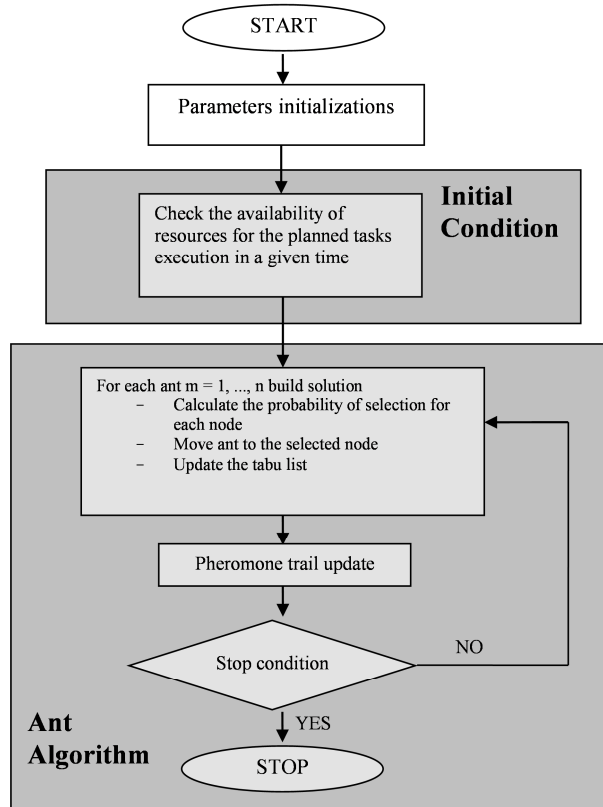


Fig. 2. Methodology of scheduling resource – constrained multiproject environment

Execution of projects in multi-project environment requires the simultaneous use of various resources, such as material, financial and human, and is subject to limited access to these resources at the same time.

In the first step creating the schedule it is necessary to check the availability of resources for the planned tasks execution in a given time. It can be done by comparing elements of two matrices first matrix representing the available resource capacity with needed capacity for planned tasks for each resource and each planning period.

$$\mathbf{a}_k^t \geq \mathbf{z}_k^t \quad (1)$$

This is the necessary condition (not sufficient) and does not guarantee the performance of the tasks on time. In this condition the precedence constraints are not taken into account. When the initial condition is fulfilled ant algorithm procedure starts (Fig. 2).

5. THE ANT COLONY OPTIMIZATION METAHEURISTIC

Ant Colony Optimization is modeled on the foraging behavior of Argentine ants. Real ants are capable of finding shortest path from a food source to the nest. When searching for food, ants initially explore the area surrounding their nest in a random manner. If an ant finds a good solution, marks its paths by putting some amount of pheromone (which is guided by some problem specific heuristic) on the edges of the path. The quantity and quality of the food will guide other ants to the food source [20],[21]. The following ants are attracted by the pheromone so that they search in the space near previous good solutions. The collective behavior that emerges is a form of autocatalytic behavior, where the more ants following a trial, the more attractive that trial becomes for being followed. The process is characterized by a positive feedback loop, where the probability with which an ant chooses a path increases with the number of ants that previously chose the same path. Pheromone evaporates with the time, and then the less used path will be much lower in pheromone concentration [22].

The Ant Colony Optimization algorithm have some major differences with a real one, it was assumed:

- artificial ants have some memory,
- they are not be completely blind,
- they live in environment where time is discrete.

Ant has to choose among different path. The choice is based on two main elements [22]:

- Pheromone trails that were heavily chosen by preceding ants are chosen with higher probability, high trial levels are synonymous with short paths.
- Heuristic is defined as the inverse of the distance, and so closer nodes have a higher chance of being next.

Ant algorithms have been applied to solve different kind of optimization problems. One of these solutions is the traveling salesman problem (finding the shortest path) taken into account by (Dorigo, Maniezzo, Coloni) [23], (Dong, Guo, Tickle) [24]. Ant algorithms were also applied to the problem of quadratic assignment (Gambardella, Taliard, Dorigo) [25], (Phen, Kuan, Komarudin) [26], the problem of determining the vehicle routes (Bullnheimer, Hartl, Strauss) [27], Çatay [28], the problem of machines layout (Corry, Kozan) [29]. Scheduling problems using ant algorithms were taken by many authors. Seo, Kim [30] considered the problem of job shop scheduling. The problem of scheduling in the flow system was taken by Mirabi [31]. The problem of scheduling tasks on a single processor was reported in Solimanpur et al. [32]. Project scheduling problem under resource constraints was considered by Zhang [33], Christodoulou [34], Chen et al. [35].

For [36], it is assumed that the algorithm achieves the best results when the input number of ants can be (k) a similar value to the number of nodes.

Also assumed that the fixed pheromone value of $Q = 1$, studies have shown little effect of this parameter on the global results of the algorithm [36]. Parameters α and β control the parameters of the relative importance of the intensity of the track and its visibility is appropriate. If the impact of pheromone (α) is equal 0, the closest activities are more likely to be selected; this correspond to a classic stochastic greedy algorithm. If $\beta = 0$ only the value of the impact of pheromone on the route is taken into account. For values of $\alpha > 1$ it leads to the rapid emergence of a stagnation situation, in which all the ants follow the same path and construct the same tour, which is strongly suboptimal [37].

Ant algorithm is elaborated to the resource – constrained multiproject scheduling problem with resources requirement and the makespan as the minimization criterion. Algorithm is written in Job Scheduler –authors own program, based on xml language. This program performs project scheduling under resource and technological route constraints using ant algorithm.

6. AN ILLUSTRATIVE EXAMPLE – DESIGN AND MANUFACTURING OF PACKAGING IN THE CONTEXT OF PROJECT APPROACH

With more and more complex distribution processes of different kinds of goods and commodities, the role of packaging in a quick, efficient and cost-effective way of moving on from the manufacturer to the customer becomes more and more critical. Their role is particularly high in the transport, in acceleration of the handling processes, in protecting the quantity and quality of goods, and in the identification of goods in the process of distribution.

The perception of the various functions of packaging, multi-stage projects, enables the conclusion, that in the packaging industry, at the stage of designing, manufacturing and testing prototypes tasks are unique, one-time, complex, and can be seen as a design task (project).

Packaging design and production is performed by companies that specialize in this kind of activity and this means that at the same time such companies will carry many similar projects.

With constraint resources they will be preparing various types of packaging (individual, collective, transport). The task is then brought to Resources Constraint Multi Project Management.

Such an approach to the design and manufacturing of packaging is reduced to scheduling concurrently executed one-time actions. Such defined multi-project approach resembles the environment with limited access to shared resources.

Considered environment is based on the parallel executed projects, between which there is no direct sequential relationship, but their dependence results from the use of common resources.

Manufacturing companies, performing production managed as a project, focus on obtaining the shortest execution time of order (project), without specifying the date of completion or setting a deadline for launching the execution in order to ensure the directive deadline. Directive term, suggested by the client cannot be exceeded, and each earlier completion of the project is a benefit to the company.

Therefore, in this study an approach to the design and manufacturing of packaging in the context of the construction of the project schedule is considered, assuming that there are not any arbitrary starting and finishing times of activities in projects that belong to the multi-project environment, and only the time required for the activity is given. Following the needs of the market, deadlines (due time) are controlled and treated as constraints, and task scheduling is reduced to the minimization of the makespan C_{max} .

It should be noted that the packaging set (individual, collective, transport) must be ready at the same time.

The ant algorithm application for generating a schedule in a system of concurrent projects is presented below and this is only an attempt of applying simple, academic example of proposed method to the packaging - this example shows the possibility of applying proposed approach. In this article, the project will be understood as the preparation and production of packaging. Concurrency is apparent from the fact that at the same time different products, or different containers for packaging (individual, collective, transport) for one product are prepared.

Tab. 1. Project 1

Activity number	1	2	3
Resource	2	3	4
Duration	3	3	2

Tab. 2. Project 2

Activity number	1	2	3	4
Resource	1	2	3	2
Duration	4	3	2	1

Tab. 3. Project 3

Activity number	1	2	3	4	5
Resource	4	2	1	3	1
Duration	1	3	2	3	2

Given is a system in which the problem of scheduling three packaging projects carried out on four resources is examined. A first packaging project consists of 3 activities, the second of 4 activities, while the third of 5 activities (Tab. 1,2,3). The table presents data on the durations of activities on individual resources for projects.

The schedule of projects, due to the optimization criterion adopted for all projects, C_{max} , is expected to be found. An answer to the question of how to deploy these activities to minimize the duration of the entire project is searched.

The proposed ant algorithm uses global pheromone trail strengthen rule - after each finished iteration of the algorithm pheromone level is enhanced in accordance with the principle (1).

The input data to the algorithm is presented in Table. 5

Tab. 5. Algorithm input data

Number of artificial ants	m	20
Parameters identifying the impact of the pheromone left on the path and the impact of heuristic value	α	1
	β	5
Pheromone evaporation coefficient	ρ	0,5
	$\rho \in (0,1]$	

At the beginning of the iteration a population of ants is created. Number of resources is adequate to the number of artificial ants inside the system. Subsequent solutions of the artificial ants are selected in accordance with a probability (1).

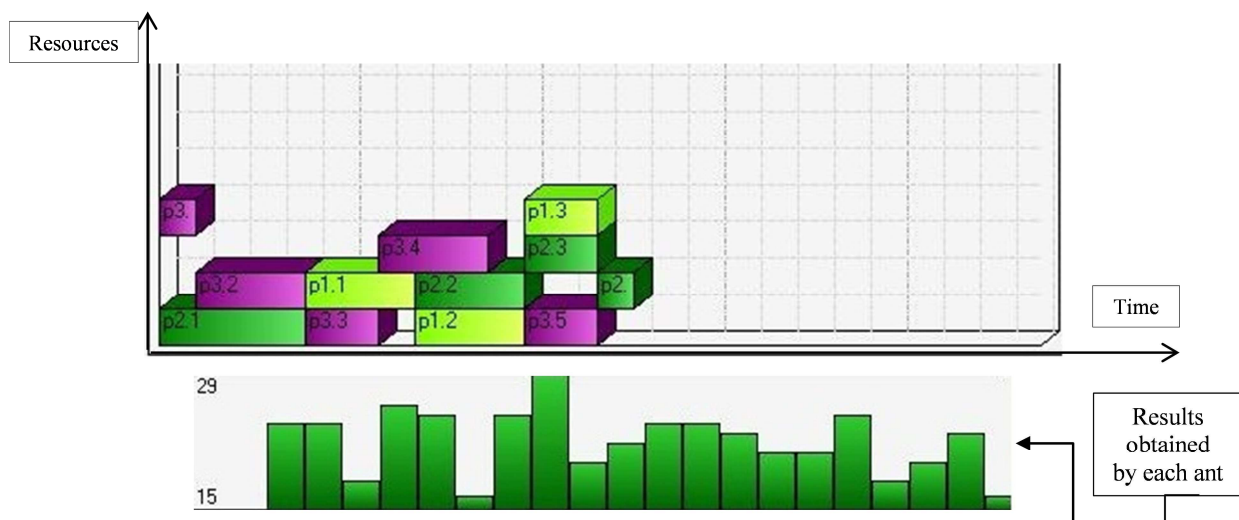


Fig. 3. Gantt`s chart for the best solution.

Pheromone evaporation coefficient has been set at a level of 0.3. The higher the ratio, the less pheromone from previous passes remains at the edges. Ten algorithm tests have

been conducted. As a result of the algorithm, in 4th test the best solution has been provided - the length of the makespan is 13 units of time (Fig. 3).

7. CONCLUSIONS

Packaging due to its highly dynamic development is one of the leading sectors in industrialized countries. For this reason, more and more companies get involved in this topic, as a result of perceiving the great potential of this area. In this paper, the problem of scheduling concurrent tasks connected with starting up the production of a new set of packages has been presented. The possibility of ant algorithms implementation for this problem has been presented. The objective function is minimization of makespan under constrained resources and due time. This paper develops an approach to use Ant Colony Optimization to the design and manufacturing of packaging in the context of solving the resources – constrained multiproject scheduling problem. The main advantage of proposed method is the ability to produce optimal and suboptimal solutions. At the same time given precedence constraints between the activities should be satisfied and resource requirements of the scheduled activities per time unit should not exceed given capacity constraints for the different types of resources. Using pheromone as a means of communication, the system builds good cooperation mechanism inside the nest.

REFERENCES

- [1] SKOŁUD B., 2007, *Operational management. Production in small and medium-sized enterprises*, Wydawnictwo Politechniki Śląskiej, 238.
- [2] LEACH L.P.J., 2000, *Critical Chain Project Management*, Artech House, Norwood.
- [3] BRILMAN J., 2002, *Modern management concepts and methods*, PWE, Warszawa.
- [4] LEACH L.P., 2000, *Critical Chain Project Management*, Artach Mouse, Boston.
- [5] WALL M.B., 1996, *A Genetic Algorithm for Resource – Constrained Scheduling*, Doctoral Dissertation for Mechanical Engineering at the Massachusetts Institute of Technology.
- [6] MINGOZZI A., MANIEZZO V., RICCIARDELLI S., BIANCO L., 1995, *An Exact Algorithm for the Resource Constrained Project Scheduling Problem Based on a New Mathematical Formulation*, in: www.csr.unibo.it/~maniezzo/pspaper.ps
- [7] KOLISCH R., HARTMANN S., 1999, *Heuristic algorithms for solving the resource-constrained project scheduling problem: Classification and computational analysis*, In: Weglarz, J. (Ed.), *Handbook on Recent Advances in Project Scheduling*. Kluwer, Dordrecht, 147-178.
- [8] LEE J. K., KIM Y. D., 1996, *Search heuristics for resource-constrained project scheduling*, *Journal of the Operational Research Society*, 47, 678–689.
- [9] J. ALCARAZ, C. MAROTO 2001, *A robust genetic algorithm for resource allocation in project scheduling*, *Annals of Operations Research*, Vol. 102, pp.83–109.
- [10] BOCTOR F. F., 1996, *An adaptation of the simulated annealing algorithm for solving resource-constrained project scheduling problems*, *International Journal of Production Research*, 34, 2335–2351.
- [11] BOULEIMEN K., LECOCQ H., 2003, *A new efficient simulated annealing algorithm for the resource-constrained project scheduling problem and its multiple mode version*, *European Journal of Operational Research*, 149, 268-281.
- [12] PINSON E., PRINS C., RULLIER F., 1994, *Using tabu search for solving the resource-constrained project scheduling problem*, *Proceedings of the 4th International Workshop on Project Management and Scheduling*, Leuven, Belgium, 102–106.

- [13] MERKLE D., MIDDENDORF M., SCHMECK H., 2002, *Ant colony optimization for resource-constrained project scheduling*, IEEE Transactions on Evolutionary Computation, 6, 333–346.
- [14] PRITSKER A., ALLAN B., WATTERS L. J., WOLFE P. M., 1969, *Multiproject scheduling with limited resources: A zero-one programming approach*, Management Science, 16, 93–108.
- [15] TSUBAKITANI S., DECKRO R. F., 1990, *A Heuristic For Multi-Project Scheduling With Limited Resources In The Housing Industry*, European Journal of Operational Research, 49, 80–91.
- [16] LAWRENCE S. R., MORTON T. E., 1993, *Resource-constrained multi-project scheduling with tardy costs: Comparing myopic bottleneck and resource pricing heuristics*, European Journal of Operational Research, 64, 168–187.
- [17] WILEY V. D., DECKRO R. F., JACKSON J. A., 1998, *Optimization analysis for design and planning of multi-project programs*, European Journal of Operational Research, 107, 492–506.
- [18] LOVA A., MAROTO C., TORMOS P., 2000, *A multicriteria heuristic method to improve resource allocation in multiproject scheduling*, European Journal of Operational Research, 127, 408–424.
- [19] BLAZEWICZ J., LENSTRA J. K., RINNOOY KAN A.H.G., 1983, *Scheduling Projects to Resource Constraints: Classification and Complexity*, Discrete Applied Mathematics, 5, 11–24.
- [20] BLUM CH., 2005, *Ant colony optimization: Introduction and recent trends*, Physics of live reviews, 2005.
- [21] DORIGO M., MANIEZZO V., COLORNI A., 1996, *The Ant System: Optimization by a Colony of Cooperating Agents*, IEEE Systems, Man and Cybernetics, Italy.
- [22] ABDALLAH H., EMARA H.M., DORRAH H.T., BAHGAT A., 2009, *Using Ant Colony optimization algorithm for solving project management problem*, IJ of Expert Systems with Application, 36, 10004–10015.
- [23] M. DORIGO M., MANIEZZO V., COLORNI A. 1991, *Positive Feedback as a Search Strategy*, Technical Report, 91-116, Politecnico di Milano, Milano.
- [24] DONG G., GUO W., TICKLE K., 2012, *Solving the traveling salesman problem using cooperative genetic ant systems*, Expert Systems with Applications, Apr 2012, 39/5, 5006–5011.
- [25] GAMBARDELLA L.M., TAILLARD E.D., DORIGO M., 1997, *Ant Colonies for the QAP*, Technical Report, 4-97, IDSIA, Lugano, Switzerland.
- [26] PHEN C.S., KUAN Y.W., KOMARUDIN, 2009, *Assessment Guidelines for Ant Colony Algorithms when Solving Quadratic Assignment Problems*, AIP Conference Proceedings, 8/13/2009, 1148/1, 865–867.
- [27] BULLNHEIMER B., HARTL R.F., STRAUSS C., 1999, *Applying the Ant System to the Vehicle Routing Problem, Metaheuristics*, Advances and Trends in Local Search Paradigms for Optimization, Eds. I.H. Osman, S. Voß, S. Martello, C. Roucairol, Kluwer Academic Publishers, Boston, 109–120.
- [28] ÇATAY B., 2010, *A new saving-based ant algorithm for the Vehicle Routing Problem with Simultaneous Pickup and Delivery*, Expert Systems with Applications, 37/10, 6809–6817.
- [29] CORRY P., KOZAN E., 2004, *Ant Colony Optimization for the Machine Layout Problem, computational Optimization And Applications*, 28/3, 287–310.
- [30] SEO M., KIM D., 2010, *Ant colony optimisation with parameterised search space for the job shop scheduling problem*. International Journal of Production Research, 48/4, 1143–1154.
- [31] MIRABI M., 2011, *Ant colony optimization technique for the sequence-dependent flowshop scheduling problem*, International Journal of Advanced Manufacturing Technology, 55/1-4, 317–326.
- [32] SOLIMANPUR M., VRAT P., SHANKAR R., 2005, *An ant algorithm for the single row layout problem in flexible manufacturing systems*, Computers & Operations Research, 32/3, 583–598.
- [33] ZHANG H., 2012, *Ant Colony Optimization for Multimode Resource-Constrained Project Scheduling*, Journal of Management in Engineering, 28/2, 150–159.
- [34] CHRISTODOULOU S., 2010, *Scheduling Resource-Constrained Projects with Ant Colony Optimization Artificial Agents*, Journal of Computing in Civil Engineering, 24/1, 45–55.
- [35] CHEN W., SHI Y., TENG H., LAN X., HU L., 2010, *An efficient hybrid algorithm for resource-constrained project scheduling*, Information Sciences, 180/6, 1031–1039.
- [36] BORYCZKA U., 2006, *Algorithms of the ant colony optimization*, Publishing house of University of Silesia, Katowice.
- [37] DORIGO M., STUTZLE T., 2004, *Ant Colony, Optimization*, Massachusetts Institute of Technology.