POLLACK PERIODICA
An International Journal for Engineering and Information Sciences
DOI: 10.1556/606.2017.12.1.4
Vol. 12, No. 1, pp. 45–58 (2017)
www.akademiai.com

RESOURCE MANAGEMENT SIMULATION USING MULTI-AGENT APPROACH AND SEMANTIC CONSTRAINTS

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Received 11 June 2016; accepted 22 September 2016

Abstract: The resource management in a dynamic environment is a really complex problem. If semantic constraints are taken into account the complexity increases significantly. The problem definition of resource management using semantic constraints in the subject domain is demonstrated by means of an example of manufacturing scheduling. The application of multi-agent approach is suggested and examined to solve the resource management problem. Experiments simulate two types of calculations of the resource allocation problem in manufacturing scheduling: the multi-agent approach and the sequential calculations. The experiments have demonstrated the effectiveness of multi-agent approach to solve the above defined problem.

Keywords: Resource management, Manufacturing, Scheduling, Multi-agent approach

1. Introduction

Goods' Production and Production Management (GPPM) [1] are characterized as sets of complex, large, dynamical, stochastic and nonlinear tasks. As a consequence it is generally very hard to manage these types of systems. Management may mean design and operation as well. The production process generally consists of part production and assembly. In this study only the part production (manufacturing) is taken into account.

Resource management [2] of complex systems is necessary to ensure the effective functioning. In a fast changing environment it is required that a complex system was adaptable and able to respond quickly to all emerging challenges. There are software packages in the market offering solutions; however they cannot provide good enough results, as they take into account only a limited set of data and constraints.

One of the reasons is that resource management is hard to overview and understands, and it needs the co-operation of several partners. Some solutions, as for example Material Resource Planning (MRP II.), or selected Systems, Applications and Products (SAP) modules offer general tools to solve different planning and related tasks. Most of these solutions attack some subsets of the Enterprise Resource Planning (ERP) problem. As SAP solutions try to be general and factory independent, they need a large effort to tailor them to a given workshop or factory. The situation is similar with Baan, Modi and with other similar goal systems and software packages [1], [2], [3].

1.1. Some earlier results

There are several planning/scheduling programs available due to the fact that scheduling concerns generally only one or a few workshops, and only a few types of activities, it is easier to manage [4], [5]. The authors in [6] deal with similar problems even in Ecology. As a matter of fact all big enterprises use their firm-specific solutions, which are not public. One of the reasons is that standardization is still missing or incomplete in the ERP and scheduling domains. Besides the common technological constraints affecting the resource management process, there is a set of ill-formalized constraints, the so-called semantic domain constraints, which affect the final result and increase the complexity of the system.

One type of the constraints relates to the fact that even homogeneous resources are differing from each other. The homogeneous resources in this case are resources of the same kind, which have the same functionality. These resources are usually considered as identical. This paper will show that these resources are needed to be distinguished to reach appropriate results. These differences should be used in the construction of a resource allocation plan. All these factors make the resource allocation problem very complex and different from traditional scheduling problems, e.g. classical production planning. In most recent cases the environment is dynamically changing and information might inherently be contradictory, fuzzy, and subjective.

The problem of resource allocation is described and solved in the studies of various authors. Some of them suggest solving this problem as a task of constraints programming. In [7] the authors provide an overview of the main production scheduling approaches for operations management. These are approaches like Genetic Algorithm (GA), Ant Colony Optimization Algorithms (ACOA), Neural Networks (NN) and others.

In [8] the authors use the GA and its modifications to manage the problem of resource allocation. They use 3 types of constraints (capability, availability and step execution order) to enhance the efficiency and quality of GA-based scheduling approach. Artigues et al. [9] suggested a constraint-based approach for the mixed task scheduling and resource allocation problem. This problem can be addressed either as a temporal constraint problem or as a time and resource constraint problem. The authors propose some new constraint propagation mechanisms to manage resource allocation for time constraints and resource sharing constraints.

Monica et al. [10] use ant colony optimization to solve the problem of resource allocation and task scheduling in software industry. Kirn et al. [11] discuss that agent-based approaches are preferable to classical scheduling methods for enterprise and healthcare scenarios. Kovács et al. made interesting studies and experiments concerning multi-agent approach and scheduling [12], [13] in 1992 and 1996. Fiorucci et al. [14] gives a general formulation of the real time optimal resource allocation as a mathematical programming problem that is relevant to forest fire hazard. Bachrach et al. [15], [16] use multi-agent to solve the resource allocation problem.

The existing approaches do not distinguish between the homogeneous resources and do not use any specific information about the problem environment, which has a significant impact on the resource allocation and scheduling. Optimal path planning has to solve similar types of problems (see [17], [18], [19] as examples), perhaps the start and end points of calculations and of the inferences are reversed in comparison with scheduling.

In resource management in complex systems in a rapidly changing environment one must meet the following requirements for applying a decision support system:

- the construction of the resource allocation plan must take into account the individual properties inherent in the homogeneous resources as they significantly affect the final results and, consequently, the efficacy of the decision-making also depends on them;
- the system should be ready for various unexpected situations that violate existing plans, and if necessary, to find and to offer the decision, support providing options for alternative solutions that eliminate these effects, with a preliminary estimate. For example, some resources used in the manufacture of parts (machines, equipment) can break down and the workers may get sick. These are typical unexpected situations to be solved by a decision maker.

In this paper an approach is suggested to the development of a Decision Support System (DSS) in the management of resources of complex systems in a rapidly changing environment with the use of semantic domain constraints. The paper consists of the following parts. First an example showing a resource allocation problem is given. Then the problem definition of resource management using semantic constraints is formulated. In the next section multi-agent approach to solve the problem is discussed. After that a lab simulation experiment is described and evaluated, and some conclusions are given.

2. An example to demonstrate the resource allocation problem

The simulated manufacturing enterprise (or plant) has machines, tools and equipment of various kinds to perform various operations, the workers of different professions and have different professional skills. Concrete tools, instruments, equipment can perform only a specific set of operations. Workers also can perform only those operations that correspond to their skills.

There is a production objective (volume of work per time), specifying which parts, how much and by when are needed to make. The process of part manufacturing is a predetermined sequence of the jobs. Each job requires a certain type of machines and/or equipment and /or tools, as well as appropriate professional skills of the workers.

2.1. The problem of resource management

A plan of parts' manufacturing has to be constructed (calculated, estimated), which is represented by a sequence of jobs for the parts manufacturing using concrete equipment with the use of a particular instrument, by concrete workers in a specific time. This plan should provide manufacturing of the required number of parts using the existing equipment, machines, tools and workers, etc. The result of the planning process will be a plan that defines the time slots of all jobs on every concrete machine (equipment) by every concrete worker for each concrete part. The goal of this plan is to allocate the available limited resources (machines, equipment, tools, and workers) for the manufacture of parts for a certain period (shift, day, week, month, year, etc.).

In addition to the above mentioned constraints, affecting the process of resource management, there are some ill-structured constraints that affect the final result. For example, two machines of the same model may differ significantly from each other. These differences may be related to how old the machines, how intensively they have been used, what kind of repairs were carried out on them, etc. Usually, this type of information is not taken into account under construction of a resource allocation plan. If, for example, two workers are considered, who have the same specialty and professional skills, there may be differences between them due to the fact that one of the workers has certain preferences, which can significantly influence his productivity. Even doing the same work or more exactly a sequence of the same jobs can influence in various ways the productivity of two different workers, which have the same specialty and professional skills.

The sequential processing of the same parts on the same machine continuously over a long time can greatly influence the worker's productivity. At the same time, this fact should not influence significantly on the productivity of another worker with the same specialty and professional skill. As a result, the first worker can require, for example, 12 or 15 hours to perform his work, instead of the planned 10 hours. This fact leads to delays in the execution of the process, thereby breaking the manufacturing plan. Besides this, resources involved in this job (a machine, tools, equipment and a worker) will be unavailable for the scheduled jobs at a specific time.

Thus, there are certain factors that are often hidden and ill-formalized, which can have significant influence on the resource management. Therefore these factors must be taken into account at the stage of planning design to avoid problems in the future when the plan is executed. It is suggested to use an intelligent system which is able to predict future productivity of the worker on the basis of processing of information about his current productivity, and the nature of his work and other information related to the production activities. This information can be collected as a result of monitoring the activities of workers, machines and equipment.

The volume of accumulated data may reach a large 'hard to manage' size. Using the technology of data mining, new knowledge and hidden patterns in the data can be identified. This knowledge can be useful, when it helps to construct the plan for the resource allocation (see *Fig. 1*) more effective.

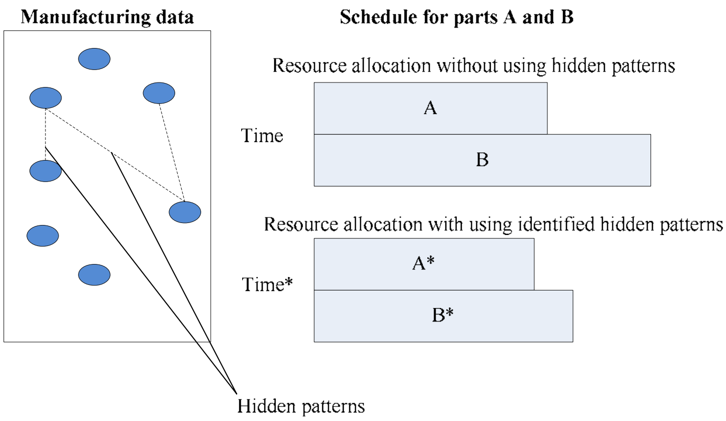

Fig. 1. Influence of identified hidden patterns in manufacturing data on the resource allocation process

3. Problem definition of resource management using semantic constraints of the subject domain

3.1. Semantic constraints

Today, in the era of Product Life-cycle Management (PLM) every manmade (or even natural) object can be taken into account as a product. This way resource planning and resource management is product, as well as manufacturing scheduling, or a real product as a car or bicycle.

During product design, designers have to make plans understandable for the potential users. Thus, being unaware of design functionality may lead to a user's inability to interact with it. There are two methods that users will depend on in order to figure out how to manipulate functions within a product's design. The first method is *affordance*, which is a list of alternative actions to be taken in order to use a product; the second one is *the constraint* method, which sets the restrictions on the alternative actions that can be taken upon using a product. Designers must incorporate these two principles into their designs in order to signal users.

There are four major types of constraints: physical, semantic, cultural and logical. These constraints are used in the construction of a design to advise the users of their limitations. Further, they explain the actions, which may be performed to manipulate a product's function. The use of semantic constraint depends heavily on the user's knowledge about the conditions where a product is used and how it relates to the physical world. Indeed, different products are being used in different conditions to carry out their functions. Users have to depend on their tacit knowledge, which is a type of knowledge that people build up based on previous experience, to determine the actions needed to be performed under a certain condition to get functions from a product. For example, the function of a car is to transport people from a point to another. The car must be running on the road and the driver must be seated facing the front in order to see the road. The actions of driving the car on the road and sitting facing the front to operate a car would be considered as a semantic constraint.

3.2. Semantic constraints in resource planning/scheduling

Next the problem of manufacturing scheduling of a workshop is considered. There are different resources (personnel, tools, equipment) on the manufacturing line, which are required to perform the technological operations. These resources are divided into categories (for example, the millers, turners, milling machines, lathes and others). One resource can belong to several categories at the same time (for example, a worker has two professions: a turner and a miller).

Table I shows an example of the main operations (processes) of the manufacturing of two parts.

Table I

Technological process of manufacturing of parts 1 and 2

	Operation	Run Time		Necessary resources
		For part_1	For part_2	
1.	Lathe	1.5 hours	1.0 hour	Turner, lathe
2.	Locksmith	1.0 hour	1.0 hour	Locksmith, hammer
3.	Milling	3.5 hours	2.5 hours	Miller, milling machine
…	…	…	…	…

In this experiment only one resource for each category of resources listed in *Table I* is available. It is necessary to manufacture 2 parts using these resources (part_1 and part_2). The possible solutions (variants) of the manufacturing plan for part_1 and part_2 are presented in *Fig. 2*.

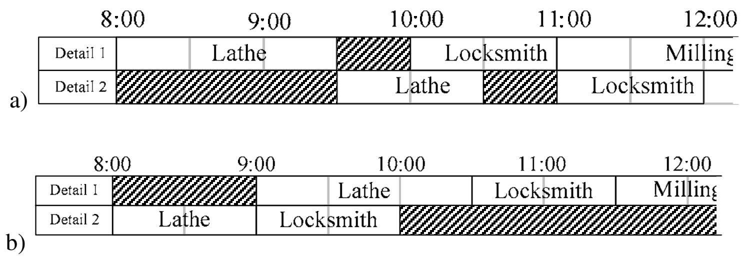

Fig. 2. Variants of fragments of the manufacturing plan for parts 1 and 2:
a) option 1 - manufacturing begins with part_1,
b) option 2 - manufacturing begins with part_2

The first two operations for part_2 (lathe and locksmith) require 2 hours. But because of the occupancy by other parts of these resources the manufacturing of part 2 takes 4 hours (see *Fig. 2a*). The total run-time of the two operations (lathe and locksmith) for both parts together was 4 hours (i.e., the end time of the operation locksmith for part 2 - 12:00), excluding InterOperation Downtime (IOD) - 3 hours (the end time of the operation locksmith for part 2 would - 11:00). *Fig. 2b* shows that for the first two operations for both parts took 3.5 hours without IOD. This example clearly demonstrates the dependence of the total execution time of the plan from the start order of the parts in the processing and availability of OID.

4. Possibilities of applying the multi-agent approach

4.1. Multi-agent systems

A Multi-Agent System (MAS) is a computerized system composed of multiple interacting intelligent agents within an environment. Multi-agent systems can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Intelligence may include some methodic, functional, procedural approach, algorithmic search or reinforcement learning. Although there is considerable overlap, a multi-agent system is not always the same as an Agent-Based Model (ABM). The goal of an ABM is to search for explanatory insight into the collective behavior of agents (which does not necessarily need to be ‘intelligent’) obeying simple rules, typically in natural systems, rather than in solving specific practical or engineering problems. The terminology of ABM is used more often in the sciences and MAS in engineering and technology. Multi-agent systems may be appropriate in online trading, disaster response, modelling, planning, simulation and design of technical systems.

Any manufacturing facility, as for example a factory or a workshop can be taken into account as a MAS if some (several) (2 to 20) computer controlled machine tools and robots and computers and other units are interconnected electronically and physically to work as a larger unit to produce different parts in given amounts during the same shift. Connections may be between computers and machine-tool controllers, and any other equipment. These will work as Communicating Agents in the further discussion - if programmed properly. These systems are generally called as a Flexible Manufacturing System or Flexible Manufacturing Cell (FMS or FMC), or Computer Integrated Manufacturing (CIM) or recently Intelligent Manufacturing Systems (IMS). The multi-agent behavior is realized through the interconnections and the software solutions providing the communication.

4.2. Multi-agent system for resource management

The application of the so-called multi-agent approach is investigated to solve the resource allocation problem in manufacturing scheduling. The most significant advantages of this approach are the following:

- it is more flexible, than other methods, as in the case of emergencies there is no need to construct new the production plans;
- there is an ability to directly monitor the execution of the plan and, if necessary, make changes in it in real-time.

More details about the advantages of multi-agent approach to resource allocation problem are described in [20], [21].

So, the following information technology tools and means are suggested to be used for the resource allocation in manufacturing scheduling: decision support system, multi-agent approach, data mining and ontological knowledge base (see *Fig. 3*). The ontological knowledge-base is perfect to represent semantic constraints of the subject domain described above. More details about ontological knowledge-base are presented in [20], [22]. Technologies of Data Mining can be used for knowledge acquisition about hidden patterns in manufacturing data. All of these technologies are used as a basis for the development of DSS for the resource allocation in manufacturing scheduling.

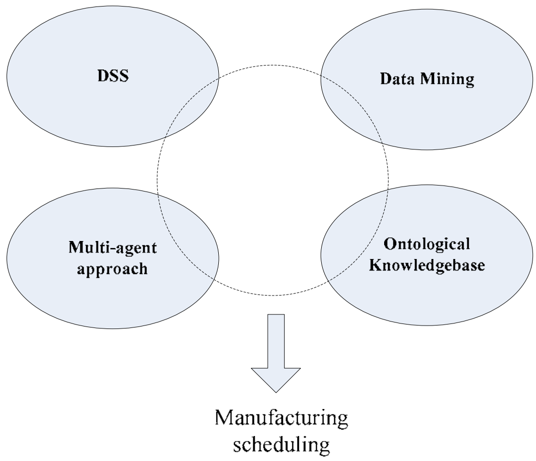

Fig. 3. Information technologies used for the resource allocation in manufacturing scheduling

In a previous work [20] a generalized resource allocation algorithm was proposed (see *Fig. 4*). The agents of multi-agent system for resource allocation play the role of consumers and/or suppliers of resources, as well as the resources themselves. The agents are forced to interact and negotiate with each other to solve the problem of resource allocation. Such interaction is simulated by the communication process.

In most cases, the problem of resource allocation is a global performance criterion that must be achieved by an appropriate allocation of resources. Then the behavior of the agents can be considered as a cooperative, because only the account of mutual interests can solve the problem. At the same time, each agent can have its own local criteria to determine the effectiveness of the solution for a particular agent. For example, one solution may be preferable over an other one based on the use of local performance measures, despite the fact that they can be exactly the same in terms of overall efficiency criterion.

Any ill-formalized semantic constraints are presented by an ontological knowledge base which is available to each agent. In addition, the agent's knowledge base is used to describe the criteria that reflect the acceptability of the resource allocation and take into account the individual characteristics of the simulated real-world objects. The agents determine the admissibility and acceptability for their decisions based on personal knowledge when negotiating.

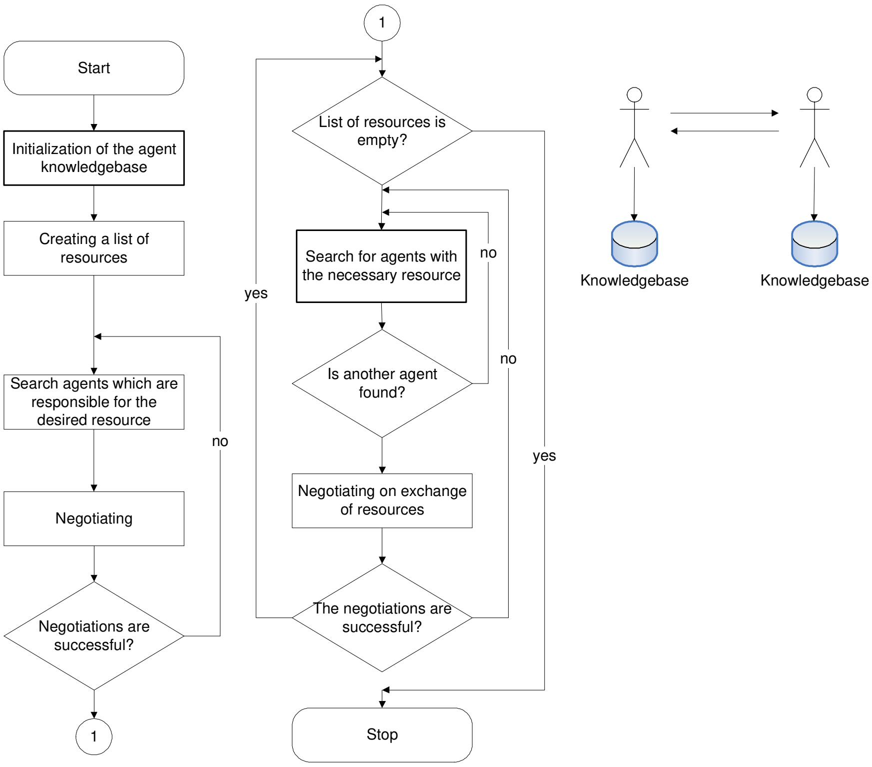

Fig. 4. General algorithm of resource allocation

The process of scheduling involves selection of resources for each operation. Choosing of resources imposes the most tedious tasks for this process.

For finding the necessary resource the following activities are needed:

- check the category of the resource;
- check the value of the parameter 'quality';
- check the setting for 'performance'.

This way all the resources are checked and the resource with a maximum value of 'performance' will be chosen.

The next problem to solve is a (common) situation when the manufacturing plan requests the production of N parts all together, at the same time. For making one part you need to perform O_n operations. The total number of operations to be performed will be equal to O. The time of the interview (revise) of one resource is T. The number of resources in the category is $S_o - R_s$. As the goal of the optimization is to decrease the total throughput time of the parts' manufacturing the resources are chosen in a way that to reduce the execution time of the operations. This can be achieved by a complete enumeration of all available resources related to the required category. Then the number of searches for resources for each operation will be equal to the sum of the quantities of existing resources of necessary categories to perform the operation.

If carry out the search for the resources consistently, as it is done by the master or planner in production, then the total time spent on the selection of resources of the one category will be $R_s \cdot T$, and the time for selection of resources for a single operation

$$\sum_{s=1}^{S_O}\left(R_s \cdot R_o \cdot T\right), \tag{1}$$

and for the entire plan

$$\sum_{o=1}^{O}\sum_{o=1}^{S_O}\left(R_s \cdot R_o \cdot T\right). \tag{2}$$

If all operations can choose the necessary resources to perform their tasks independently, that is, the selection of resources began to occur parallel, then the time for this would be significantly reduced and equal to

$$\max_{o=1...O}\left(\sum_{s=1}^{S_O}\left(R_s \cdot R_o \cdot T\right)\right). \tag{3}$$

Then each operation can be presented as independent agent (able to work independently) and find everything it needs for its work. In a personal computer the necessary agents are implemented as separate independent threads of the same class (type), which are endowed with different mechanisms for interacting with each other or (if there are) other classes of flows (agents). In the computer the amount of calculations are limited by the number and performance of processors. In the case of sequential selection of resources between operations of the processor of selections will 'intrude' extraneous tasks. This situation is not going to happen or extraneous insertion will be minimized in the case of parallel operations (*Fig. 5*).

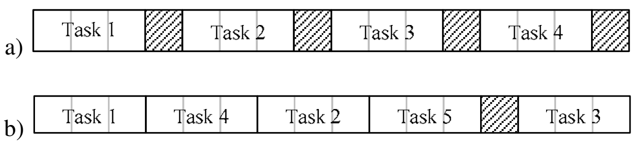

Fig. 5. Comparative scheme of a) the serial and b) the parallel resource allocation

When the task of resource allocation is using a sequential method, the distribution is approximately the following: the task of selecting resources for all operations consists of many similar tasks (in *Fig. 5* are: Task1, Task2,...) that are executed strictly in order, by the installed software.

Run-time distribution on a computer may perform various extraneous tasks and background processes of the computer, which takes a lot of CPU time (*Fig. 5a*). All these third-party tasks and processes are performed by the processor alternately with ‘useful’ tasks (in *Fig. 5* this is shown by shaded areas): the task to be performed arrives to the processor allocated to it, and then it is put into the queue. After its execution a new task from a number of resource allocations arrives and queued.

But the third-party tasks and processes can ‘intrude’ in the queue of the processor at the moment when the first ‘useful’ task is executed. This leads to the fact that the execution time of the next useful tasks may be shifted to a later time. In the case of parallel distribution all tasks arrive to execution in the form of separate independent threads, the execution sequence of which are not regulated. And then they act as extraneous tasks, that are queued into processor almost simultaneously, i.e. during the execution of one ‘useful’ task other ‘useful’ tasks can be put in the queue of the processor. Thus, third-party jobs will have fewer opportunities to take processor time.

4.3. The task to be performed

In view of the specific manufacturing the following types of agents were allocated:

- agent ‘part’ is the object that must be made as an end product;
- agent ‘operation’ are actions that you must perform to produce the part or perform one step of the processing cycle;
- agent ‘resource’ are performers, equipment, tools and so on - all that is necessary to perform technological operations to manufacture the part.

In order to obtain a quantitative comparison, an experiment was done where 5 jobs were issued, with specified various technologies of manufacturing parts (see *Table II*).

Table II

The results of the experiments

A	B	C	D	Run time			
				PC №1	PC №2	Average	‘Actual time’
1	1	15	15	15.523	15.461	15.492	0.492
2	2	7 + 8	15	8.234	8.214	8.224	0.224
3	3	5	15	5.219	5.178	5.199	0.199
4	5	3	15	3.180	3.161	3.171	0.171
5	15	1	15	1.141	1.112	1.127	0.127

Abbreviations on top of the columns 1 to 4: A - Number of Jobs; B - Number of Parts; C - Number of Operations in the Processing Technology; D - Total Number of Operations

In this experiment the work of agents ‘operation’ was simulated for choosing of required resources. As the number of required resources for each operation may be different, and the time for choosing the resources may also vary, therefore, to meet the ‘purity’ of the experiment, the procedure of the selection of resources is replaced by a time delay of 1 second. 1 second was chosen as it corresponds to an average time for choosing of resources in simulation [23].

The operation starts, performs the chosen delay, register one and passes the baton to the next operation in technology. If it is the last operation, then the run time of choosing of resources is fixed for all operations in manufacture of the part. So to obtain the time spent by the CPU-only for 'useful' tasks (without choosing of resources), it is necessary to take off the time of choosing resources multiplied by the maximum number of operations in the technologies of parts of the entire job from the execution time of the total job.

The experiment was carried out 100 times on two different computers:

Intel Core i5-2500 - 3.30 GHz, RAM 3,49 Gb, OS– MS Windows XP x86;
Intel Core i3-2100 - 3.10 GHz, RAM 4 Gb, OS– MS Windows 7 Ultimate x64.

Since the total number of operations is the same for all jobs, there is an inverse dependence between the execution time for one job and the number of concurrently running threads in this task (*Fig. 6*).

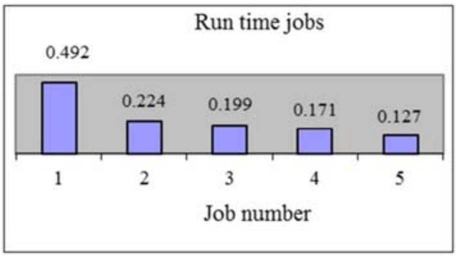

Fig. 6. Chart of run-time jobs

The experimental results presented in *Table II* and *Fig. 6*, demonstrate a decrease in computation time with increasing number of agents at a constant number of tasks. So, the time is decreased from 0.492 seconds for only one working agent to 0.127 seconds with 15 simultaneously working agents. The 4 times acceleration of the agent's work can be observed. Thus, the experiment confirmed the appropriateness of applying the multi-agent approach for a certain type of resource allocation problem.

5. Conclusion

The paper considers the problem of resource management in manufacturing scheduling in a dynamic environment and having semantic constraints. It is suggested to use multi-agent approach to solve this complex problem. Experiments were carried out to demonstrate the effectiveness of the application of multi-agent approach to rich appropriate solution. The examples, which demonstrate the usefulness of the suggested methods, are of restricted size and complexity. It is in first line of the authors' plans for the short-term future to check the applied programs with the above given algorithms on industry-size, real problems. As soon as any results are collected they will be published to inform the reader and the community.

The other key areas for further research is to develop a prototype of DSS for management in manufacturing scheduling, and to make an analysis of the effectiveness of the proposed approach.

Acknowledgements

The research is supported by Grants RFBR 14-07-00811-a and 15-07-01565-a.

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