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INTELLI 2015

The Fourth International Conference on Intelligent Systems and Applications

ISBN: 978-1-61208-437-4

InManEnt 2015

The International Symposium on Intelligent Manufacturing Environments

October 11 - 16, 2015

St. Julians, Malta

INTELLI 2015 Editors

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INTELLI 2015

Forward

The Fourth International Conference on Intelligent Systems and Applications (INTELLI 2015), held between October 11 - 16, 2015 - St. Julians, Malta, continued a series of events on advances towards fundamental, as well as practical and experimental aspects of intelligent systems and applications.

The information surrounding us is not only overwhelming, but is also subject to limitations of systems and applications, including specialized devices. The diversity of systems and the spectrum of situations make it almost impossible for an end-user to handle the complexity of the challenges. Embedding intelligence in systems and applications seems to be a reasonable way to move some complex tasks from user duty. However, this approach requires fundamental changes in designing the systems and applications, in designing their interfaces and requires the use of specific cognitive and collaborative mechanisms. Intelligence becomes a key paradigm and its specific use takes various forms according to the technology or the domain a system or an application belongs to.

The conference had the following tracks:

- Intelligent human-computer interaction systems
- Intelligent applications and systems
- Intelligent agents
- Formal ontology and semantics
- Intelligent robotics
- Hybrid artificial intelligent systems

The conference also featured the following symposium:

- ***InManEnt 2015, The International Symposium on Intelligent Manufacturing Environments***

Similar to the previous edition, this event attracted excellent contributions and active participation from all over the world. We were very pleased to receive top quality contributions.

We take here the opportunity to warmly thank all the members of the INTELLI 2015 technical program committee, as well as the numerous reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors that dedicated much of their time and effort to contribute to INTELLI 2015. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations and sponsors. We also gratefully thank the members of the INTELLI 2015 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope INTELLI 2015 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the area of intelligent systems and applications. We also hope that St. Julians, Malta provided a pleasant environment during the conference and everyone saved some time to enjoy the beauty of the city.

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Multi-Agent Technology in Real-time Intelligent Resource Management Systems

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Abstract—**The article describes the main principles of intelligent real-time resource management systems based on the use of multi-agent technology. Features of the new generation of systems are demonstrated that implement the full cycle of autonomous resource management, from reaction to real-world to monitoring deviations between the plan and the fact on the basis of the developed multi-agent platform. The article also presents several applications of scheduling systems in various areas, including cargo flow management for the International Space Station, workshop management in machine-building enterprises, railway traffic and cargo transportation management. Adaptability of multi-agent systems to external disruptive events is demonstrated. Finally, the similarities between multi-agent systems and non-equilibrium thermodynamics of Ilya Prigogine are described.**

Keywords-multi-agent technology; resource management; dynamic scheduling; real-time; demand-resource network; adaptability

I. Introduction

Methods for enterprise resource planning, which would give the possibility to quickly, flexibly and effectively make smart decisions reflecting a balance between interests of many participants in the conditions of growing complexity of the modern world, play a crucial role in a variety of different applications.

In this regard, it is not surprising that development of computational algorithms for allocation, planning and optimization of resources is moving towards development of adaptive resource management systems suitable for rapidly changing conditions of the modern environment, although the software market is still dominated by batch systems in which orders and resources are known in advance and do not change in the course of computation.

In contrast to the classical large, centralized, indivisible and sequential software programs, multi-agent systems (MAS) are set up in the form of distributed groups of small autonomous software objects running asynchronously but concurrently in order to produce the result.

Multi-agent technologies are increasingly gaining the position of one of the most innovative tools for real-time planning for a wide range of tasks. Scientific and practical bases of multi-agent approach to solving complex problems and building distributed systems began to take shape in the last decades of the 20th century at the junction of artificial intelligence, object-oriented and concurrent programming, Internet technologies and telecommunications.

Multi-agent technologies are at the heart of recent developments [1]-[4] making it possible to respond to the challenges which modern systems are facing nowadays. They give the possibility to present the process of solving any complex problem (in this case – resource management) as a process of self-organization and searching for a balance between opposing interests of basic demand agents and resource agents, implemented through mechanisms of negotiation with concessions on the basis of market mechanisms of service delivery.

The article is organized as follows. Section II describes the multi-agent approach which is applied in Smart Solutions products, and summarizes modern state of traditional and multi-agent approaches to resource planning. Section III deals with application of the developed multi-agent methods to scheduling of cargo flow and flight program of International Space Station, planning of a group of spacecrafts for Earth remote sensing, real-time railway traffic management of Russian Railways, and cargo transportation management. Implementation efficiency of multi-agent systems in these domains is proved. Section IV provides a method of adaptability evaluation of real-time multi-agent systems. Section V outlines a thermodynamic approach to description of multi-agent systems. In Conclusion results of successfully implemented methods by Smart Solutions are given as well as further steps in multi-agent system development.

II. Multi-agent approach to solving the problems of adaptive planning based on demand-resource networks

Solving traditional resource planning tasks is usually formulated as a batch process, where all orders and resources are known in advance and do not change in the process of work [5][6]. At present, traditional ERP-systems (Enterprise Resource Planning) has included more and more resource schedulers often called ASP methods (Advanced Scheduling and Planning), which are developed by such companies as SAP, Oracle, Manugistic, i2, ILOG, J-Log, etc.

However, such systems implement, as a rule, batch linear and dynamic programming, constraint programming, and other methods based on combinatorial search of variants [6], which appear to be of little use in practice. To reduce complexity of combinatorial search, new heuristic and metaheuristic methods are used [7], which give the opportunity to obtain appropriate results in a reasonably short period of time due to reducing combinatorial search variants.

Besides, one can use “greedy” local search methods, simulated annealing, constraint programming, taboo search, genetic and ant colony algorithms, etc.

The stated methods also use batch processing. They are hardly extended by additional target criteria and do not allow considering various factors which are often used in real life, which can be set not only by formulas and in equations, but also by tables and diagrams.

Moreover, search of variants in real data takes up too much time, though the results are usually quite improbable and hardly comparable to decisions made by people in real life.

From the very beginning multi-agent technology has been used for solving traditional optimization tasks with the use of distributed decision making approaches, for example, Distributed Constraint Optimization task (DCOP) [8]. Besides, several bio-inspired methods have been developed for solving resource scheduling problems, for example swarm optimization, hybrid methods based on artificial immune system and Particle Swarm Optimization (PSO) [9][10].

One of the new approaches is built on bio-inspired distributed problem solving of resource scheduling problems based on multi-agent technology with economic reasoning [11][12].

Despite the fact that PSO is a powerful stochastic evolutionary algorithm, its disadvantage is that it can lead to a local optimum. In order to increase algorithm productivity, various methods are suggested, for example, improvement of initial swarm characteristics [13][14]. In the multi-agent optimization method with adaptive parameters [15], it is suggested to modify the range of speed changes to avoid speed increase, which will allow for reducing search time of the optimal decision.

Besides, PSO algorithm modification – Two-swarm Cooperative Particle Swarm Optimization (TCPSO) [16] that uses two swarms “driving” and “driven” will give the opportunity of increasing adaptability level of swarm intelligence.

The application of evolutionary algorithms and swarm optimization algorithms, in particular, in multi-agent systems allows to solve problems of high complexity that cannot be solved by other ways, due to the combinatory rising computations complexity [17].

The multi-agent approach is used primarily for solving multi-criteria planning tasks, including quality of products or services, time for their implementation, price (prime cost), risks, etc. In the proposed approach, the system itself chooses goals for improving the vector of its parameters, based on the achieved results and the current situation with orders and resources. As its primary objective for improving its condition the system chooses the criterion having the worst indicator values. Implementation of multi-agent approach in development of an intelligent system for dynamic planning is based on the concept of demand-resource networks and the method of conjugated interactions for real-time enterprise resource management on the virtual market [1]-[3].

According to this concept, each request, order or other demand as well as each resource (production resource, machinery, equipment, vehicles, personnel) are assigned to software agents that negotiate with other agents and plan order fulfillment "just-in-time" (JIT) or "as soon as possible" (ASAP). This ensures support of collective coordination and decision-making in real time at various stages of planning and production plan execution in the various subdivisions working together to solve common problems.

Planning is done in several interrelated stages: if changes are made at one of the stages, it is necessary to make adjustments at all subsequent stages. Some examples of such external influences are changes in the cost of resources and orders, changes in the schedule of materials deliveries, equipment failure and so on. But on the other hand, the resource itself receives proposals from various claims (demands) and decides which of the orders are more suitable for it.

These decisions can not be made once and for all and are not made that way. They can be reviewed and modified as the situation is changing and new events are happening in real time. At the same time, new connections established between agents cause changes in operating conditions for other agents, and thus define the process of system self-organization leading to restructuring of the schedule in response to emerging events. The result is considered to be achieved and the system completes its work only when none of the agents have opportunities to improve their state, the time for finding a solution has run out, or the user has interrupted the process in order to enter interactive mode.

Multi-agent technology makes it possible to create software agents that are trying to optimize their target parameters. For example, an order in a factory or in a cargo company wants to be executed just in time and at minimal cost, or a resource (machine, truck, etc.) wants to be used as efficiently as possible and have no downtime or overwork. Agents at first do it "selfishly" (independently), without asking anyone – that is why they manage to do it very quickly if resources are available. However, if the decisions of other agents create conflicts, they are able to negotiate, make concessions and seek a solution (consensus) in favor of the mutual interest that unites them (for example, a worker or a driver, a workshop or a car fleet).

This approach can be considered an example of Disrtibuted Problem Solving, in which a complex task is decomposed into subtasks that can be solved independently, but then the solutions obtained are combined and detected conflicts are solved.

III. Industrial applications of multi-agent systems in SMART SOLUTIONS during 2010-2015

A. Multi-Agent System for Scheduling of Flight Program, Cargo Flow and Resources of International Space Station

This project was commissioned by S.P. Korolev Rocket and Space Corporation (RSC) “Energia” with the goal of solving the challenges of flight program and cargo flow planning for the International Space Station (ISS) [4]. The multi-agent system provides interactive support for the following tasks [18]:

Flight program design, that results in distribution of space ships' docking to ISS across modules and time considering various constraints:

- Cargo flow strategic and operational scheduling that results in distribution of deliveries of units, blocks and systems across transportation flights and manned spacecraft;
- Fuel deliveries and both strategic and tactical scheduling based on a forecast of ISS position changes, Sun activity, operations plan and flight program;
- Water, food and other supply delivery scheduling based on information about the expeditions and flight program;
- Scheduling of items returned to the surface and disposal of waste items;
- Flight crew time scheduling.

The main feature of the system is the adaptive scheduler of cargo flow following the real time changes in demand. New cargo orders may displace those already allocated, but with lower priority or delivery deadline.

The system constructs the flight and cargo plan after taking into account the availability of space on the next spacecraft to be launched, available space on board of the station, disposal of existing cargo, which provides more available and other factors, while allowing the user to adjust the results manually.

The results of the implementation are as follows:

- The system made it possible for the first time to keep track of redundant or missing equipment aboard the station.
- The time required for scheduling cargo flow for a duration of one year has decreased from 176 to 8 hours, and the time for its approval - from 264 to 88 hours.
- Keeping the current cargo plan up to date saves up to 200 hours per year.
- Preparation of reserve flight plans for emergencies takes 320 hours less per year.
- The time for allocation of one spacecraft's cargo aboard the station went from 264 down to 128 hours, for a total of 544 hours per year for "Progress" spacecraft and 320 hours per year for "Soyuz" manned capsule.
- Automatic verification of lists of cargo for disposal eliminates duplicates and saves about 312 hours per year.

Fuel balance planning, water and other supply balance planning and crew's working schedule allocation all take 10%-15% less time, for a total of 270 hours per year.

B. Smart Satellites: System for Management of a Group of Spacecrafts for Earth Remote Sensing

A multi-agent system for management of target usage of spacecraft groups for Earth remote sensing has been developed. Smart Satellites makes it possible to adaptively redistribute sensing tasks among the spacecrafts within groups [19][20].

The space system is represented as a heterogeneous multi-agent system in which agents are represented by spacecrafts for Earth remote sensing, satellites-retranslators which serve to ensure operational communication between agents and, finally, ground stations. Management is implemented through coordinated interaction of spacecrafts: the satellites dynamically form a team, distribute among themselves the task and solve it in parts, depending on their location and of on-board equipment capabilities. To formalize the description of the desired object an ontology is used which is presented in the form of a semantic network.

The experimental results showed that the use of multi-agent management can reduce the total time of sensing in complex dynamic environments, and ensure viability of the system in case a number of spacecrafts leave the group.

C. Smart Railways:Railway Traffic Management System

Smart Railways, a distributed intelligent system for real-time railway traffic management, commissioned by the Russian Railways, is aimed at building and adapting multilinked and multilevel schedules for operation of Russian Railways subdivisions in case of unforeseen events, including the schedules for high-speed, passenger and cargo trains, locomotives , stations, crews of locomotive drivers [21]. Intelligent system for management of passenger railway traffic is developed to control the traffic of high-speed "Sapsan" trains. The system builds the initial master-plan and then makes adjustments under the influence of occurring events, such as, for example, maintenance work on track sections. The logics of reaction to events is implemented as follows: each event starts a chain for rescheduling of resources in the system. Moreover, proactive optimization of plans is carried out in order to search for better options while there is still time for the system operation.

The developed system makes it possible to achieve the following important indicators:

- almost no delays of high-speed "Sapsan" trains;
- building the whole schedule takes up to 45 minutes;
- reaction to events - up to 30 seconds.
- All the main safety requirements are met (intervals between trains, no crossing of bulk cargo trains and high-speed trains, etc.) - 99%,
- technical requirements (acceleration and breaking time, choice of platforms, standing times) - 97%.
- The average delay became less than 8% (up to 30 trains in conflict);
- the average time for return to the master-plan became 1.5 times less.
- Productivity of dispatchers' work increased by more than 2 times.

D. Smart Factory: Multi-agent System for Workshop Management in Machine-building Enterprises

The multi-agent system "Smart Factory" is designed to increase productivity and efficiency of factories by means of adaptive resource allocation, planning, optimization and monitoring of machine assembly workshops in real time [22]. The system gives managers the opportunity to input information on new events and start rescheduling, as well as to connect or divide operations and adjust the plan, initializing a chain of automatic changes to the plan.

These solutions increase efficiency of the factory in the following way:

- machine load is increased by 20%,
- output per 1 worker is increased by 30%,
- observation of contracts and terms of product output as well as transparency of production processes are increased by 90%,
- operational cost control is increased by up to 100% in real-time mode,
- actual production cycle is reduced by up to 30%,
- stocks of finished goods and stock reserve are reduced by up to 15%,
- complexity of scheduling and forecasting results of the factory operation is also reduced.

E. Smart Trucks: Multi-agent System for Cargo Transportation Management

Smart Trucks, a multi-agent system for cargo transportation management, was designed for a customer with its head office in Moscow and more than a dozen branches across the country. The customer organizes cargo transportation using its own fleet of over 100 trucks and more than a hundred outsource carriers involved [23]. The system implements the full cycle of resource management in real time and provides the capability to automatically control the business process of application receipt, loading and unloading of cargo through communication with the driver via a cell phone. The driver must input the start and end signals for corresponding operations (loading, transportation, unloading).

As a result of implementation of the system during the first year of its operation

- the number of completed orders has increased by about 4.5%,
- utilization ratio of the trucks belonging to the customer’s own fleet has also been increased,
- the number of delays to the customer has been reduced by 3.5%,
- complexity of calculations and the number of errors has been reduced,
- idle run of each truck has been reduced by 3-5%,
- downtime of trucks has been reduced by 5-7%,
- fines and penalties have been reduced by 2-4%,
- and there was also growth of other important indicators of resource utilization.

IV. ADAPTABILITY OF MULTI-AGENT SYSTEMS

Agents interacting with each other in the demand and resource system, form a solution of a complex general dynamic schedule task by dividing it into simple parallel tasks of placing orders at resources. When the current state is getting worse, the agents focus on mitigating the impact of negative external effects. Agents of demand and resource network improve their own states locally and, thus, provide an increase in indicators of the whole system, for example, overall satisfaction.

When a new order, not distributed by the system, appears, the system satisfaction decreases at first, as the coming agent does not find the best position immediately. Only some time later, the general satisfaction starts increasing due to rescheduling and improvement of agent states. The system enters the state of non-equilibrium, and then agents aim at achieving a new local equilibrium state. In order to assess dynamics of multi-agent system, calculating the average satisfaction of demand and resource agents is suggested depending on time.

The adaptability degree of multi-agent system γ is introduced, which reflects the rate of local equilibrium recovery

$$\gamma=(y_2-y_1)/T, \tag{1}$$

where γ is a minimal value of satisfaction after impact, y_2 is the average satisfaction of system agents after impact, T is the time needed for equilibrium recovery of the average satisfaction y_2, see Figure 1:

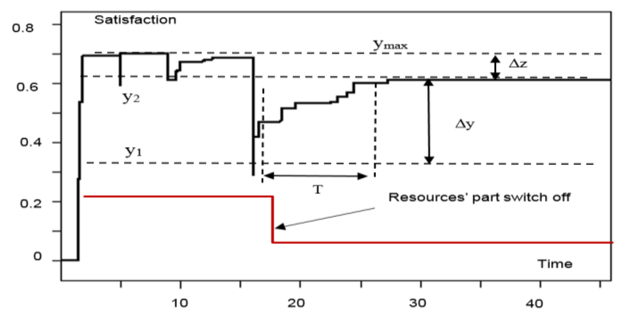

Figure 1. Adaptability of the system depending on partial resource switch off.

After maximum decrease of the average satisfaction to y_1 level, the system turns to a new quasi-equilibrium state y_2 after the time period T, and Δz is nonrecoverable lost satisfaction.

Partial recovery effect can be observed not only when resources are switched off, but also when new task flows occur discontinuously. The higher the adaptability rate, the higher the ability of agents to self-organization in elimination of negative effects.

V. THERMODYNAMIC DEMAND – RESOURCES NETWORKS SCHEDULING MODEL

Even scheduling for a small organization is a much more complex and dynamic task than it may first seem. Processes of self-organization are very similar to those described in the works of Ilya Prigogine and they play a very important role in scheduling within the developed systems [24][25].

Schedules in complex systems are to be considered as "unstable equilibriums" which means that they have different strength in different directions. Each new order brings in the money that plays the role of energy in the system. The system demonstrates such non-linear events as order and chaos, autocatalytic reactions, fluctuations, etc. When the number of conflicts waiting for resolution increases and so does the number of messages in the system, it is assumed that the temperature of the schedule in this section is increasing as well. In order to support the schedule structure, agents pay some tax that dissipate part of input energy.

If the orders stop coming into the system, the schedule will later gradually break down starting with the weakest connections between the agents. Then the system will transition into the state of chaos having zero energy and eventually it will cool completely.

VI. CONCLUSION

The paper contains a review of multi-agents systems developed by SEC "Smart Solutions" from 2010 to 2014. It demonstrates that even today multi-agent systems make it possible to solve complex tasks and design industrial systems for resource management of a fundamentally new class, which are based on the main principles of self-organization and evolution. The developed methods and instruments for designing multi-agent systems can be applied for solution of a wide range of complex tasks – from cargo delivery to the International Space Station to railway transportation. This proves the high efficiency of the developed approach. Implementation results confirm evaluations made earlier which are the evidence of increase in efficiency of using resources by 20-40% by means of real-time decision-making. Implemented projects illustrate important advantages of the approach, such as service level increase, opportunity to solve very complex tasks of scheduling and resource optimization in real time, high operational efficiency and flexibility of solutions, reliability and viability of developed systems as well as minimization of risks for enterprises.

ACKNOWLEDGMENT

The study was supported by the Ministry of education and science of Russian Federation.

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