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"Smart Factory": Intelligent System for Workshop Resource Allocation, Scheduling, Optimization and Controlling in Real Time

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Abstract. The paper describes intelligent system "Smart Factory" which is designed to increase factory productivity and efficiency of resources utilization in real time (including equipment, manpower, materials, etc.).

The objectives and key areas of application are considered and it is shown that system provides flexible event-driven reaction on changes in factory environment, resource allocation, scheduling, optimization and controlling in real time. The developed method of adaptive resource scheduling, main functionality of system and examples of screens are discussed.

The results of implementation and measured benefits for Izhevsk Axion Holding are presented.

Introduction

Intelligent system "Smart Factory" is designed to increase factory productivity and efficiency of resources utilization in real time. This objective is achieved by flexible event-driven reaction on changes in factory environment, resource allocation, scheduling, optimization and controlling in real time.

The system can be applied for machine-production factories which can be characterized by ongoing innovations, complexity and dynamics of operations as well as high uncertainty in supply and demand which require high level of adaptability in reaction on unpredictable events in real time. It is also useful for capturing specific domain knowledge on manufacturing process, products and materials, equipment and workers and to provide the individual approach to each order or resource, handle frequent changes of product / technology settings, to produce small series of different products, according with the diverse skills of workers who continually respond to unforeseen events such as new VIP order coming, equipment failure, delay in materials, etc.

In this paper we describe the concept of designed method of adaptive resource scheduling, main functionality of system and examples of screens, as well as the results of implementation and measured benefits for Izhevsk Axion Holding, one of the biggest Russian manufacturers of electronics.

State of the Art

In spite of significant progress regarding development of theory of optimization [1-2] and large-scale Enterprise Resource Planning (ERP) systems, opportunities of the enterprises on development of adaptive scheduling systems remain very limited.

Traditionally the ERP systems include subsystems of orders collection, large databases for orders and resources, accounting and reporting subsystems and a lot of other components. However, in these systems batch or manual scheduling of orders is supported, that was already discussed above. The schedulers offered by such large companies, as SAP, Oracle, JDA, i2, ILOG, Preactor and others usually realize various versions of Constraint programming methods, based on combinatory search of options in depth, for example, branch and bounds method [1].

To reduce the number of options considered in combinatorial search, new methods use various heuristics and meta-heuristics (the term "heuristics" is usually understood as a set rules, defining what option is the best, and "meta-heuristics" means the rules to choose heuristics), allowing to provide good decisions for reasonable time and reducing search iterations [2].

At the same time, even in the view of considered methods and tools of local search of variants require greater expenses of memory and time for producing schedules. For example, producing of the optimum plan for the large transport company in one of available software packages takes about 8-10 hours. During this time the volume of orders can be essentially changed that will require starting planning all over again. Meanwhile, the technologies for planning in real time remain rather primitive, and the opportunity of flexible adaptation on the base of happening events refer mainly to the opportunity of manual plans updating. As a result, according to the estimations of transportation logistics experts, the created schedules are feasible only on 40%, which compels many large transport companies still to contain staff of very skilled and expensive operators on planning and to carry out time consuming manual or semi-automatic planning.

This, certainly, is promoted by both high complexity and labor intensity of planning, unpredictability of dynamics of event stream, by requirements of an individual approach to each order and resource, constant change of conditions of functioning of the enterprise forced by clients and competitors, and also necessity of the account of many other very specific features in each business. For example, dispatcher of factory workshop should constantly keep in mind all orders with their delivery days, dependencies between operations, individual preferences and constraints of workers and equipment, etc.

As a result, many of existing classical methods of planning and resource optimization have a number of very important limitations in practice:

- Do not consider complexities of the modern business operating in thousands of orders and resources, supporting interdependency between all operations, reflecting and balancing interests of many parties involved, having a lot of their own features;
- Do not provide opportunities for adaptive planning in real time which requires dynamic event-driven conflict solving in schedule;
- It is usually supposed that all orders and resources are identical but in practice they all have their own individual criteria, preferences and restrictions, which can change during the system work (service level, time of delivery, costs and profits, risks of delivery, etc.);
- Do not give the tools for the acquiring knowledge which are specific to every enterprise, influencing quality of provided schedules;
- Do not allow an operator to explain and adjust decisions easily and in convenient way.

All these reasons not only reduce productivity and efficiency of existing methods and tools but also in many respects discontinue their practical use.

The method of adaptive scheduling based on multi-agent technology

Unlike traditional enterprise resource planning systems operating mainly in batch mode with daily-weekly-monthly cycles of scheduling, the proposed system is event-driven and working continuously in real time on server, adaptively re-scheduling selected resources which are affected by events and propagating chain of changes in production plans.

The main screen of user interface of the system is presented on Fig.1.

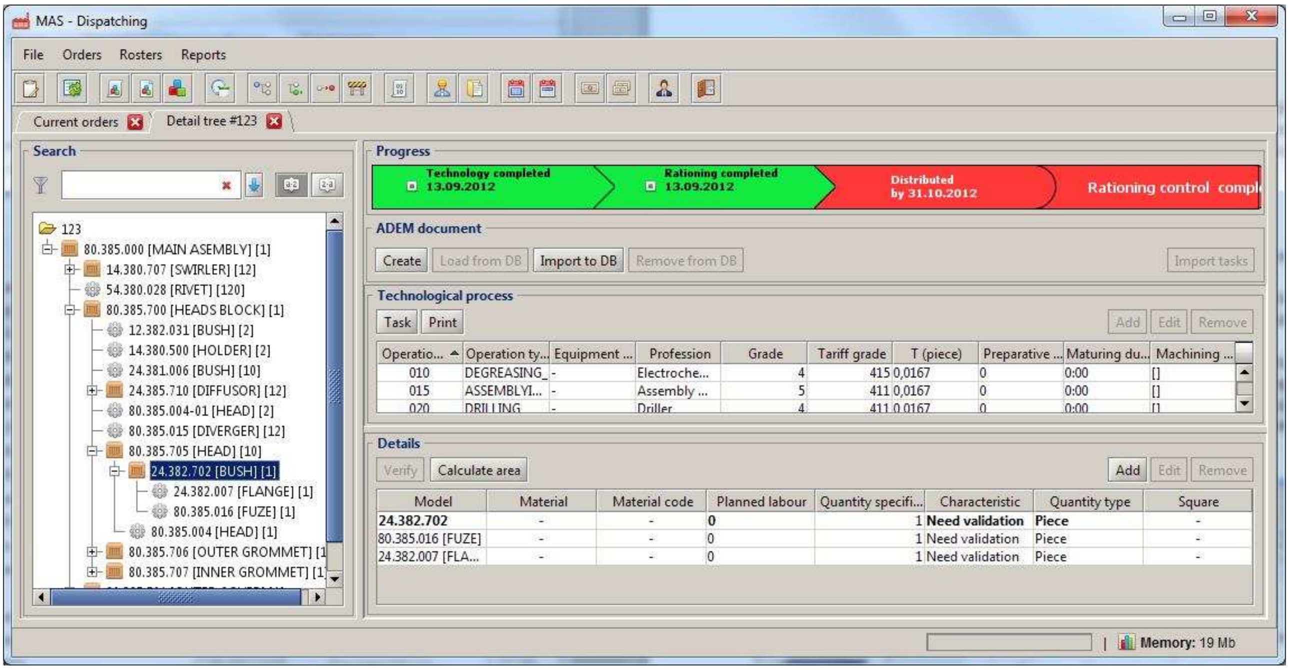

Fig. 1. New order screen showing the sequence (workflow) of main technological process.

The system provides fast respond to new events coming and also proactively improves operation plan by the use of free machine time or worker slots, by the chain of shifts and reallocations of previously scheduled operations to other resources.

The developed adaptive method of real time scheduling is based on multi-agent technology [3-4] with the use of manufacturing ontology, which includes typical classes of equipment, specifications of product structure and technological processes (sets of linked operations), workers skills, etc. In this approach software agents represent interests of orders, resources, workers, machines, operations and materials, using relationship between the operations (Fig. 2).

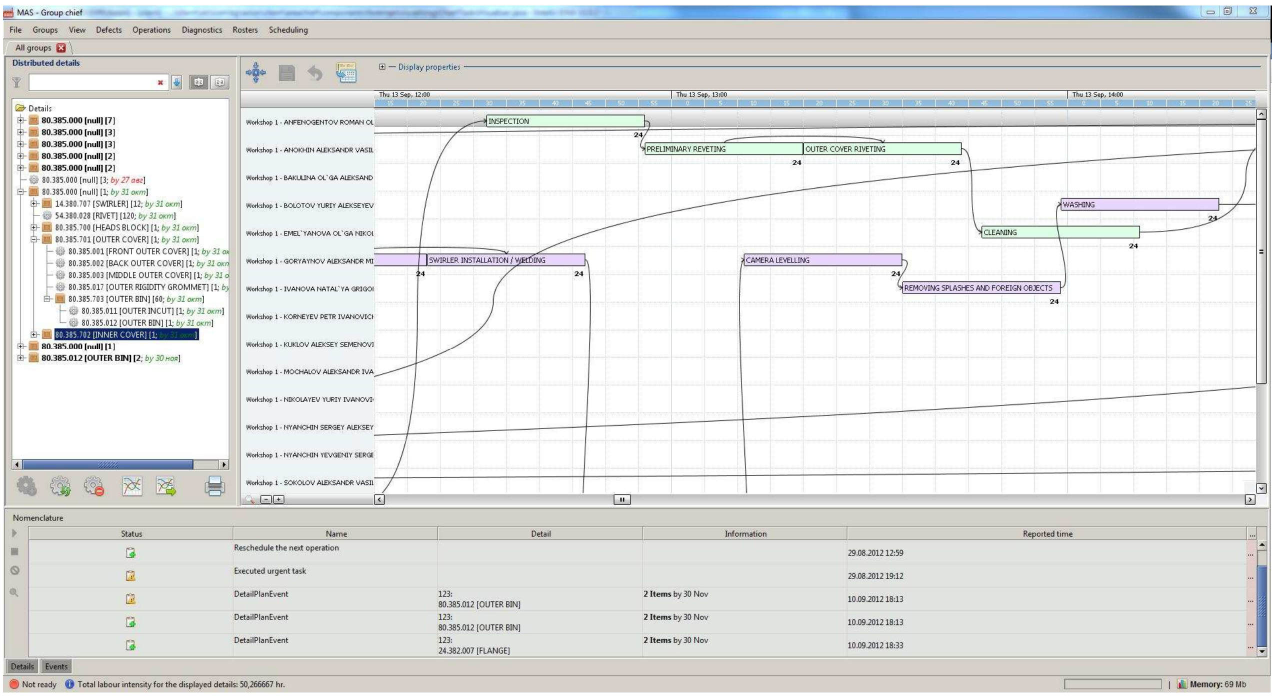

Fig. 2. Network of scheduled operations (on the left - event window).

As a result, the work plan of the workshop is built not as just output file of data produced by a classical combinatorial search, but as an active network of operations which represents unstable balance of interests of all involved parties which is achieved by negotiations of agents. During these negotiations system takes into consideration current state of plans, importance of orders, structure of products, technological processes, specifics of workers and equipment, materials and instruments availability, sequences and time of operations.

If needed, the dispatcher of workshop can intervene this active plan interactively at any time and provide smart manual rework of schedule by drag & drop of operations - and the plan will be automatically revised and re-scheduled.

The results of scheduling are presented on touch-screen terminals which support interactive communication with managers, foremen and workers (Fig.3).

All these features provide opportunity to significantly reduce complexity of scheduling and make it faster, more adequate, accurate and reliable.

Fig. 3. Touch-screen terminal for workers.

Users can simulate the new orders coming and check how it can be placed in the current production plan and how this order can affect other orders, for example, shift or even push out the less important orders.

The user can also see a number of reports (Fig.4) and how much new order production can cost according with current performance of the enterprise resources.

System functionality description

The proposed system works as an autonomous system and provides support for full cycle of resource management:

- Specification of machines, processes and technology workflows;
- Automatic import of product & technology workflows from CAD systems;
- New orders or other important events input at any time;
- Evaluation how the new order will affect the previous orders, already planned and launched into execution;
- Possibility to check the cost of this order under new circumstances;
- Ability for adaptive and flexible reallocation and re-scheduling of resources;
- Proactive optimization of the production plan (in case of time available);
- Visualization of the constructed plan in real time;
- Support for application of different scheduling strategies with different criteria;
- Interactive improvement of plans for all resources;
- Communication with users for coordination;
- Assigning workday tasks to every worker in real time;
- Monitoring and controlling of tasks execution;
- Registering feedback from workers on tasks execution;

- Operational control of production plan execution vs. plans;
- Re-scheduling in case of growing gap between plan and reality;
- Automatic reports on business radar in real time.

The system also can be integrated with existing programs, such as warehouses, payroll workers, material accounting systems, etc.

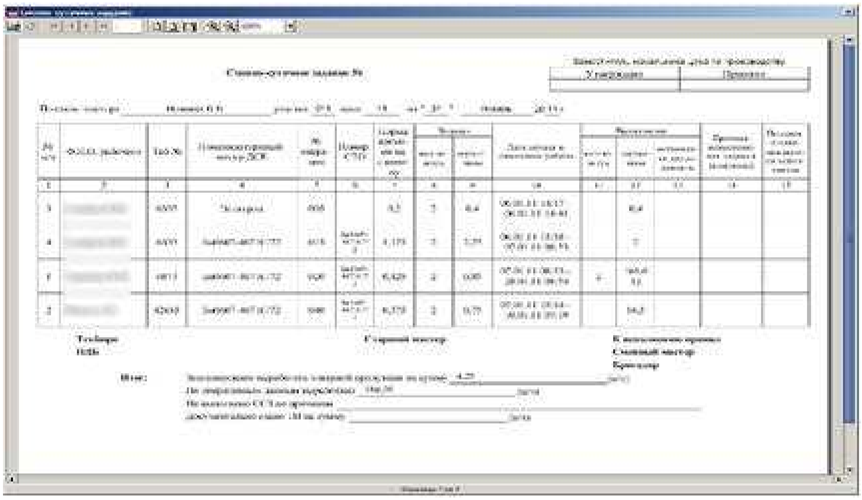

Fig. 4. Report on results of day targets

Results of implementation for Izhevsk Axion Holding

One of the successful implementations of "Smart Factory" was for Izhevsk Axion Holding (for workshop of instruments) – one of the biggest Russian electronics manufacturers:

- The number of employees in the workshop (sharpeners, electroplating, smiths, grinders, cutters, grinders, fitters, turners, millers, etc.) – 120.
- The number of workstations (lathes, grinders, milling machines, grinding machines, drilling machines, boring machines, ovens, presses, etc.) – 290.
- Order flow: every day in the workshop up to 60 new orders come.
- Assortment of products: appliances, molds, dies, special tooling, millings, packings, conductors, etc.
- The average complexity of one order execution - 35 hours.
- The maximum complexity of one order execution - 4000 hours.
- The workshop productivity monthly - is about 17 000 hours.
- Number of incoming products for assembly – up to 150.
- The number of nested levels in product hierarchy - up to 10.

Currently about 30 users work with the system every dail including workshop management team, dispatchers, technology engineers, controllers, etc. The management team of the factory and the workshop was interviewed several times during the period of 10 months of "Smart Factory" operational use - to define key results of the project.

Summarized results are the following:

- Through the use of the system it became possible to increase the workshop gross by 5-10% (depending on month) with the same number of resources.
- The project catalyzed fast transition from paper to the digital workshop management; transparency of the workshop process got about 100% which allowed better resource utilization and control; processes of scheduling are fully automated now resulting in increased productivity of workshop;
- The system is integrated with the factory ERP and workers' wages are calculated with the view on plan vs. fact analysis;

- Fast reaction on unpredictable events is provided (new order, breakage of equipment, etc.). The workshop plan is continuously updated by events so it becomes more realistic, can be used for forecasting of “bottlenecks” for orders vs. resources; all resources and orders are scheduled individually;
- The decision-making process became more flexible and reliable, valid and accurate, human factor free; complexity of the workshop resource management was significantly reduced because daily tasks for workers were generated automatically and also could be easily modified in an interactive way.

According to the top management of the factory the main result of the project was the achieving full transparency in the planning of the workshop resources that allowed seeing ahead all of the "bottlenecks" and to react quickly in order to re-plan workshop resources in real time, which led to the significant increase in resource use efficiency.

The resulted savings provide full return of investments (ROI) in about 1.4 years [5].

Conclusions

Intelligent system “Smart Factory” provides efficiency of decision-making in real time to improve customer service, reduce costs and time, business risks and penalties.

The next step of system development is to design an adaptive p2p network of workshop schedulers interacting with each other using Service-Oriented Architecture with Enterprise Service Bus – with the objective to support high performance, scalable and flexible architecture for big manufacturing enterprises.

Expected increase of resource use efficiency about 15-25% annually is guaranteed.

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