Multi-Agent System "Smart Factory" for Real-time Workshop Management: Results of Design & Implementation for Izhevsk Axion-Holding Factory

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Abstract

This paper describes the results of design and implementation of a multi-agent system for real time scheduling and controlling in the Izhevsk Axion-Holding Factory. Lessons learned, key measured benefits of solution and perspectives are presented.

1. Introduction

Industrial application of multi-agent real-time systems for operational scheduling and control of resources can bring valuable benefits for enterprises [1]. The vision, architecture and functionality of our multi-agent solution "Smart Factory" for real time workshops resource management are described in [2-3]. In this paper we will describe results of design and implementation of multi-agent application of our solution for workshop management for Axion-Holding Factory – one of largest Russian Manufacturers of electronics in Izevsk city (called "MotorFactory" - in the past).

In second part of paper we describe history of project and lessons learned in process of such kind of complex system delivery. In third part of paper we present benefits of solution measured in the process of interviews with factory management. In fourth part of paper we present the future vision and roadmap of the system.

The experience gained from the project allows us:

- to estimate the scope and complexity of tasks, time for design and implementation of similar systems;
- name the main problems and difficulties the users and developers faced with during implementation phase;
- to evaluate the efficiency of solution and outline the prospects for the development and use of the system.

Measured results and lessons learned in industrial application will be useful for validating and proving benefits of multi-agent technology for modern factories in future R&D works and industrial applications.

2. Project History

Main stages of the project history are listed below.

2.1. Collecting Product Requirements and defining Statement of Work for developing scope of additional functionality: March - June 2010 (3 months)

The first stage was aimed for collecting additional product requirements from factory end-users and defining Statement of Work for developing additional scheduling functionality, integration, reports, etc.

Instrument production workshop which serves all other workshops and makes external orders was selected as a first workshop because of problems with operational scheduling and high costs of operations.

This workshop requires every day operational scheduling of 30-40 orders for products with 20-30 components and 15-25 tasks (operations) per product for about 120 workers specialized in different types of mechanic operations, including assembly, polishing, etc.

The project was launched on March 2010 and in 3 months of work all requirements and scope of work were specified – to make additional developments and advance functionality of previous version of "Smart Factory" system developed for one of the workshops of Federal State Unitary Enterprise "Central Design Bureau - Progress", which produces rockets and sputniks, and then implemented at JSC "Syzran Tyazhmash", which produces metal-heavy machines [1-2].

2.2. Development of a specific version of the "Smart Factory" system for workshop management: July - December 2010 (6 months)

The additional developments of basic system took about 6 months including:

- Real time scheduler decision making logic customization;
- Designing new tools for allocating workers to tasks based on specification and ranking worker skills;
- Advancing of real time scheduler functionality, for example, for example, re-scheduling re-production and re-assembling process for defective products;
- Registration of ready and delayed tasks which triggers re-scheduling and helps to combine scheduling and execution;
- Interactive user interface for new types of users including technologists, controllers, etc;
- Integration with the CAD/CAM "ADEM" system that provides information on a product's hierarchy and other details of its manufacturing process;
- integration with the customer's existing ERP system of factory for salary calculations, etc;
- additional various reports for real time resource management.

The key screens of system are presented on Fig. 1-4.

As it is shown on Fig. 1 all orders for workshops are displayed with the current order status and with different filters for sorting orders. Statuses of orders: not started, planned, started, executed, in the preparation process, stopped, delayed, postponed, etc.

Fig. 2 is showing how structure and assembling technology for manufactured product can be loaded to the system from PDM system.

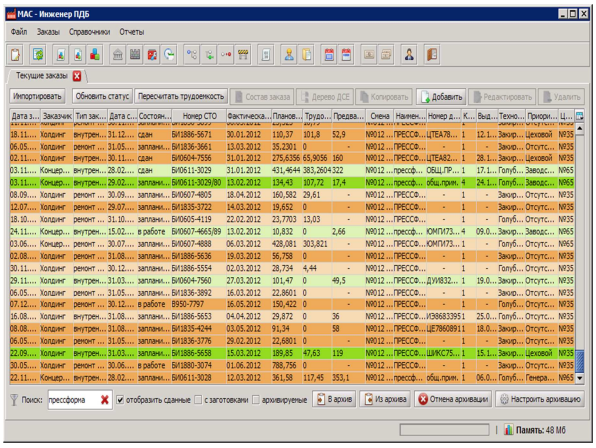

Figure 1. Statuses of Orders

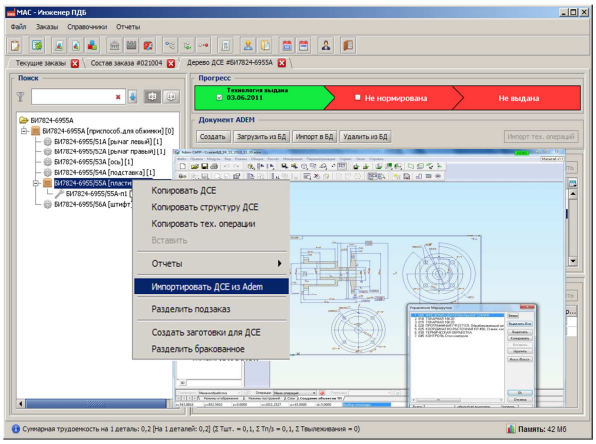

Figure 2. Loading Design of Product for Order

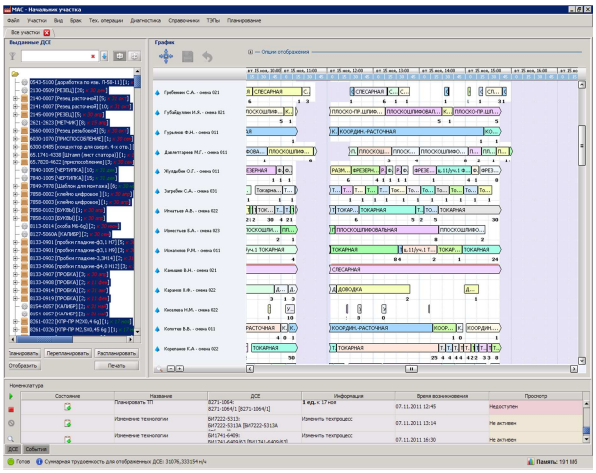

Figure 3. Queue of Events and Schedule of Workers

Event Queue gives possibility to users to enter information of new events and start re-scheduling as it is shown on Fig. 3, for example, entering new order for manufacturing loaded product (hierarchy components of which is visualized on the left).

On Fig. 4 combined Gantt and Pert diagrams are presented which shows interdependencies between manufacturing operations. User can select any operation here and “drag and drop” it on different worker as well as merge or split operations and adjust plan by this event triggering automatic chain of changes in schedule accordingly. In case that worker has not enough skills for operation or it may cause delays and other problems system will highlight this operation in red color and give warning message to user.

List of tasks for workers can be generated and printed in traditional form or presented on kiosk with touch screen for direct interactions with workers.

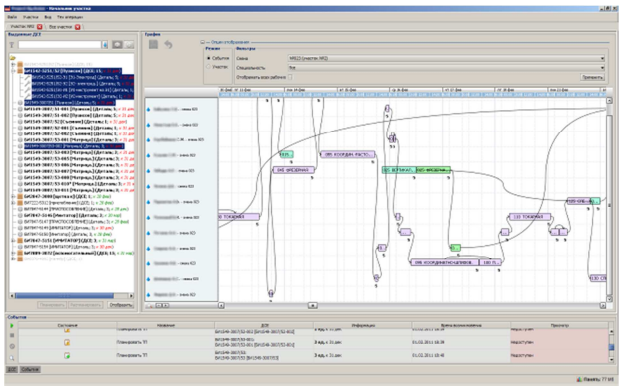

Figure 4. Interactive adjustment of workshop schedule

2.3. System installation, deployment and logic tuning, operational use: January - August 2011 (6 months)

Deployment of the system began from the installation of computers and servers, initial training of end-users, shift from paper-based business processes to electronic business processes.

In parallel we have started validating scheduling logic using real life data samples and after that operational use of system has started. But even on this stage the client requirements were constantly refined by the customer, primarily in the real time scheduling logic and usability issues. The combination of all these factors led to the delay in completion of the project by almost 4 months compared to the original project plan estimate.

As a result 352 additional requirements were received from end-users during first operational use stage and 221 of them led to changes in system functionality.

2.4. Additional developments of the System: September - December 2011 (4 months)

After full scale implementation of the system and start of operational use of system, an additional requirements and specification to expand system functionality was prepared because of new user needs discovered during the operational use of the system.

The new functionality mainly concerned: user interfaces for additional types of end-users for example, for real time resource allocation and tasks tracking and control; schedules archive support; transport matrix support; delivery of a partially completed orders; improve of system performance.

New version of system was deployed to client which is now in full scale operational use.

3. Results of Operational Use

Currently about 30 users work with the system daily 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:

- The project catalyzed fast transition from paper to the digital workshop management; transparency of the workshop process got about 100% which allows better resource utilization and control; processes of scheduling are fully automated now resulting in increased productivity of workshop;
- The system is integrated into 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 and became 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, free from human mistakes; complexity of the workshop resource management is significantly reduced because daily tasks of workers are generated automatically, and also can be easily modified in interactive way.

According to the top management of the factory the main result of the project is achieving full transparency in the planning of the workshop resources that allows to see ahead all of the "bottlenecks" and react quickly to re-plan workshop resources in real time, what leads to a significant increase in resources efficiency.

The most important measureable benefits of multi-agent technology for the workshop management:

- Through the use of the system became possible to increase the workshop gross by 5-10% (depending on month) with the same number of resources.
- Reduction of stuff routine work with documents saves 14 working hours every day (prior seven persons were engaged with this work for minimum 2 man-hours daily).

- Ability to analyze the period of every order delivery across all orders makes possible to more clearly assess the risks and obtain forecasts for several months in advance. Before the system implementation 128 man-hours per month for all participants were spent for this activity.
- Re-use of technology process of production helps to save about 23 man-hours per month.
- Automated analysis of schedules saves 256 man hours per month. Automated analysis and forecast of workload and productivity of workers for 2-3 months horizon saves 48 man-hours per month.
- Generation of every day plan for workers took 2 working days for 4 people in the past. Now it takes minutes and saves 64 man-hours of work per month.
- Automated scheduling, monitoring and control of orders execution vs workers every day plans reduce the complexity of work for management team saving 528 man-hours per month.
- The analysis of the current allocation of workers vs orders and specialization of operations for defining future needs in the workers of certain specialization saves 36 man-hours per month.

As a result, the system implementation in workshop saves 1163 man-hours per month, or 7 person-months and 84 man-months annually. With the average salary of about 40 000 rub. in a month it turns to 84 * 40 000 rubles = 3.36 million rubles savings a year.

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

4. The future vision and roadmap

The multi-agent system for real-time workshop management differs significantly from the traditional well-known batch schedulers and optimizers, providing adaptive real time scheduling according to many unforeseen events. In “Smart Factory” this very important new feature combined with monitoring and control of execution of plans in real time and lead to re-scheduling of shift-day tasks for workers daily or even more often. In addition, a number of new requirements and functional features were identified during the project which define future vision and roadmap of solution:

- The system could be equipped by touch screens for workers to mark the work performed and touch pads for masters to re-schedule “on the fly”;
- The support of real time economics is must-be option: any new order can be analyzed by the system taking into account the "impact" to the entire production plan and influence the other orders. The system can also show and take into account the cost of each transaction, each component of the product, every minute of delay, energy consumption, etc.;
- Decision making process on scheduling requires use of “knowledge base” for collecting specific preferences and constraints for use of materials, equipment, workers, operations, etc.;
- Multi-criteria harmonization (vs optimization) is required that help to balance interests of all users involved in decision making process with elasticity of criteria which help to override constraints;
- A network-centric platform for building adaptive P2P networks of real time schedulers for all workshops of the enterprise is required [4];
- The list of users can be expanded now because many of them need to have their plans strongly connected and coordinated with production plans.
- Smart capacity planner for workshop and factory as a whole is required to work on complex products and large scale (up to 3-5 years) planning horizon;
- Simulation system is required to run in parallel with real time operations – to have “what if” games. For example, user can simulate the process of new orders coming - to check different ways of solving the problem by introducing new equipment, extra shifts of workers and overtime payments, etc;
- Workshop management requires a business radar for ongoing analysis of the situation in the workshop and continuous forecasting for the early detection and solving of "bottlenecks" with resources;
- Future cooperation with client programmers requires development of a domain-specific high-level programming language to adjust scheduling logic without changing the source codes of solution.

These new features will significantly help to increase key features and efficiency of solution.

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