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DISTRIBUTED MANUFACTURING SYSTEM CONTROL IN THE IMPLEMENTATION OF MANUFACTURING STRATEGY FOR MASS CUSTOMIZATION IN FURNITURE INDUSTRY

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Abstract: *Scope of work is operative control the activities of subcontracting park, creating contract furniture through the implementation of a strategy for mass customization.*
The main objective of the work is to develop a concept for a operative control system of distributed manufacturing system for creating contract furniture. System must ensure synchronization of the production activity of seven subcontractors involved in the implementation of manufacturing strategy for mass customization.
To achieve the goal at the beginning of the work are analyzed the characteristics of distributed manufacturing systems. We studied the characteristics of operative control of distributed manufacturing systems. At the end of the work is presented a developed conceptual solution for operative control of the activities of subcontracting park, creating contract furniture. The developed system is based on the integration of ERP, APS, MES and SCADA. Tracking of material flow is performed by RFID, QR and barcode stickers..
Key Words: ***Mass Customization, Furniture industry, Distributed manufacturing systems***

1. PROBLEMS IN THE FURNITURE ENTERPRISES

Currently, in all industrial sectors and especially in furniture industry the globalization and technical innovations change the way in which the business organizations create, distribute and maintain their products. The globalization and economic crisis create new markets and new ways for supply of the manufactured furniture. This is a precondition for finding new consumers, sells growth as well as emerging of new competitors, unfamiliar consumer requirements, merciless price pressure and extreme increase of the global distribution complexity. In order to adapt to this market without borders, furniture manufacturers should apply a number of contemporary principles and concepts for lean and for agility, aiming continuous elaboration of the methods related to business process management. The main objective is raise of business efficiency, considerable improvement of the product quality, minimizing of waste, cost reduction, shrinking of the lead times for new product development.

In order to achieve these ambitious objectives in the conditions of the contemporary dynamic business environment, the furniture manufacturers introduce in a fast pace information and communication technologies in more and more traditional business processes by applying intellect in the business operations on each level of the hierarchy.

2. LOGIC OF THE MANUFACTURING RESPONSIVENESS AND COMPLEXITY

Responsiveness on the level of manufacturing system is a meaningful motivation factor for the development of modular distributed systems. Manufacturing responsiveness may be defined as the ability of a manufacturing system to respond to the dynamic conditions (originating inside or outside the business organization) which affect the production objectives [1] Therefore, the responsiveness includes ability to respond to changes in consumers demand, to damages of production equipment or delays in supplies of materials. Responsiveness implies either adaptation of the manufacturing system in order to respond to the new conditions, or compensation of the effect of change while maintaining the performance. A number of contemporary researches [1,2,3,4,5,] outline the increasing need of responsiveness as an important problem for the efforts of the business to be competitive in the changing market conditions. The capability of prompt reaction is perceived as a key mechanism for achieving competitiveness in the contemporary business environment.

In a nut shell, we should outline that we need better solutions for:

- Management in conditions of increasing change and increasing production concussions;
- Management in conditions of increasing processes complicity and increasing products variety;
- Economically efficient management in conditions of shortening life cycles of the products.

A number of developments for achieving of modularity engender specific requirements for the future integrated systems for operative production control. The key problem of the modular (autonomous) and distributed manufacturing systems is that the systems for operative production control should possess the capability not only for local operative control (feedback), but also certain freedom to take decisions at local level. This should help to the production site in the distribution of priorities, tasks or in defining the optimal number of strategies in dynamic operation conditions.

3. INTEGRATION OF MANUFACTURING SYSTEMS AND DEVELOPMENT OF NETWORKS

Over the last years arose new industrial paradigms like reaction to the speedy socio-economic changes – concepts for saving (Lean), agility, etc. The emerging of virtual enterprises or virtual organizations is a natural consequence of the evolution of the collaboration processes aiming to gain additional skills, resources for getting benefits by the market opportunities. In this manner can be formed partnership networks of the best available competences. The collaborative network organizations are dynamic structures, which are based on cooperation, competitiveness, worldwide superiority and agility. These organizations identify and take advantages of new business opportunities, support innovations and strengthen the partnership competences.

There are various new methods for design which cover the needs for design of the production systems (enterprises).

There are models for achieving interoperability between enterprises, aiming to identify and structure the dependencies, problems and notions for interoperability. Nevertheless, on the basis of comparison the concepts of these models should be harmonized and gathered in a unified logical model.

Today, main objects of attention are four directions: adaptive manufacturing; digital manufacturing; knowledge based manufacturing; networked manufacturing. The two key requirements for a manufacturing system are: real-time efficiency (ability to find and react to changes and disturbances in the internal and external environment); ability for interoperability. Complicated production structures (ranging from machines and robots utilities to production systems) now more than ever are designed as autonomous but capable of cooperation and collaboration objects which share value added activities. The main direction in manufacturing today is customization of mass products.

The main problems to be resolved are: integrated production planning and scheduling; real time operative control; management of distributed cooperative (collaborative) systems. As a response to these questions are developed the following concept solutions:

- Integrated production planning and scheduling: mathematic models from the research of the operations (theory of the queues, linear and integer programing); artificial intelligence (programing based on restrictions); evaluation of the decisions quality; parametric, scalable modules for production optimization; functioning of the systems like e-service;
- Real time operative control: modeling of disturbances and change of sensitivity; automatic registration of situations and relevant support for problem resolution; algorithms for reactive and proactive scheduling and manufacturing systems for production operative control; integration of active identification devices (RFID) in the production control;
- Management of distributed cooperative systems: Multi-agent systems; ontologies for exchange of information related to manufacturing; negotiation mechanisms and communication protocols. Models describing the production networks; analyses of networks behavior; models of efficient behavior.

In order to resolve the industry problems, there is a transition from the paradigm for total integration to the paradigm for interoperability. The standardized activities which are focused on interoperability are in the very beginning and many efforts are pending in future. There are models for interoperability of enterprises and identifying and structuring of problems and knowledge about the operative compatibility [6].

The integration between business organizations is a working practice for many enterprises, especially network enterprises or participants in large scale supply chains (the so called extended or virtual enterprises).

Long term strategic directions for interoperability between the enterprises are: development of functionality for interoperability service, which doesn't depend on certain informational technologies; multiplying of the effect of web technologies for providing services for interoperability; knowledge-based cooperation for gaining mutual benefits from the practice of the virtual organizations; scientific base for interoperability with vision and instruments for long-term problem resolution.

Facing the contemporary problems, design of enterprises should be directed to developed concepts, instruments and techniques for verification, validation, qualification and accreditation [7].

4. MODULAR DISTRIBUTED MANUFACTURING SYSTEMS

Generally, in production activities modularity is included in order to increase the operative flexibility in relation to the scope of functionality as well as in relation to the capability to configure easily when encountering changing conditions. Modularity always leads to scattering of functionality (not always territorial scattering). Modularity is not a new concept in manufacturing activities. There are many examples for modular distributed systems - systems for operative control, systems for projecting the activity of the manufacturing equipment, systems for management of the human resources. Current examples for these systems are:

- Development of systems for operative management: modular, distributed operative management of the operations through distributed systems for operative management, systems for operative control operated by systems for data acquisition (SCADA) and based on programmable logic controllers (PLC);

- Design of the activity of the manufacturing equipment: localization of the manufacturing activity through flexible manufacturing cells in custom managed, disassembled manufacturing units for Build-to-Order;
- Operative management of the human resources: increasing autonomy of the executors in the production systems ("Hoshin") and self-governing teams;
- Design of the activity of the industrial enterprises: using the developed informational technologies through methods of the so called „Virtual Manufacturing systems".

Each one of these modular distributed developments contributes for better flexibility, but not always leads to better manufacturing performance of certain production site or the whole production system.

5. OPERATIVE CONTROL OF PRODUCTION SYSTEMS

The application of more automation, information and communications for operative control of the production systems within the e-enterprises brings about many new problems. The objective is to achieve intelligent operative control and integration between many mechanic and electric systems, mechatronics, manufacturing execution systems (MES), multi-agent systems (MAS), socio-technical systems, e-technologies, etc. The purpose of these is to achieve digital operative control with further agility of the production chains from design, through production to maintenance and service. This should cover the whole life cycles of all products and processes. This new period of development is known as „Digital manufacturing" and its main directions are: modeling and experimentation of logistic and manufacturing processes in the frames of the organizational networks; automation of manufacturing through networks; mutually dependent systems for collaborative operative control; systems for operative control based on discrete events; e-manufacturing systems. [8].

The main directions which should be focused are:

- Intelligent manufacturing systems;
- Interrelated manufacturing systems;
- Network collaborative manufacturing systems;
- Agent-based decentralization and automation.

The optimization of complex production systems covers many complicated tasks, which may be classified in the following groups: [9]

- Optimization of parameters;
- Optimization of strategies for operative control;
- Optimization of layout of the production system.

In order to improve the layout of the production system, one should take many decisions about multiple parameters and strategies for operative control. In this kind of optimization we shouldn't try to achieve global optimum but alternative configurations of the production systems, which provide rational, suboptimal results. The optimization of parameters is related to production parameters like number of the vehicles for interoperation transport, size of the transport lots, etc. Most of the times, changing parameters can be achieved with minimum efforts even in operating production systems.

The optimization of the strategies for operative control helps for the elaboration of the orders distribution (mapping) and coordination based on time (scheduling). We can change the strategies for service, certain priorities and decisions for the execution of some orders in different work centers. The change of strategies for operative control requires more efforts and sometimes significant changes in the software for operative control before the start of its regular manufacturing.

The optimization of the production system layout is related to positioning of separate production equipment units. In many cases the range of possible decisions is restricted by the available resources and marginal conditions. Significant changes in the layout structure require strong efforts which make sense only in planning of new production systems or complete reorganizations of the existing production systems.

Figure 1 presents a model for optimization [9]. The levels of optimization are interrelated and changes on certain level always affect all other levels connected with it. If the optimization is performed only on one level, it can be implemented very fast but this doesn't lead to satisfactory decisions.

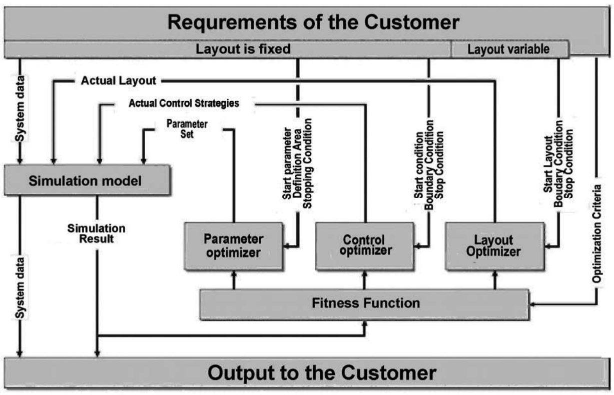

Fig. 1. *Optimization of Parameter Settings, Control Strategies and Layout Variants [9]*

6. SUBCONTRACTING PARK FOR PERFORMING MASS CUSTOMIZATION IN CONTRACT FURNITURE

The suggested by the author solution for a production system design and the links between the different suppliers is presented on figure 2.

As it may be seen from the figure, the suggested decision for development of supplier park is based on the common activity of seven suppliers (subcontractors).

This activity is planned and coordinated by one contractor who supports the contacts with the clients of the contract furniture.

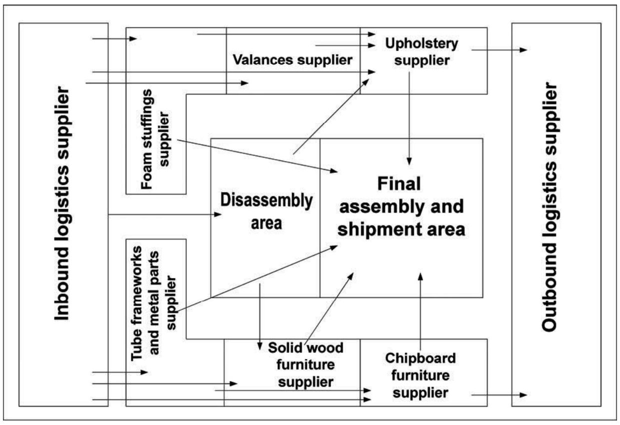

Fig. 2 *The suggested by the author solution for a production system design*

On the basis of the contracts with the clients and the obligations in them the contractor elects top designers of contract furniture and reliable suppliers of raw materials and components. The main purpose of the contractor is to transform designers' projects into engineering solutions, which may be distributed between subcontractors in the supplier park. Another main obligation is planning and scheduling of the whole manufacturing process and its decomposition to orders (operational plans), delegated to the individual subcontractors according to the requirements of the relevant contract furniture construction. With the help of a manufacturing execution system (MES) the contractor controls the performance and the deviations from the plans for each subcontractor.

In the suggested solution for supplier park are included seven subcontractors with complementary competences: chipboard furniture supplier; solid wood furniture supplier; upholstery supplier; valances supplier; foam stuffing supplier; tube frameworks and metal parts supplier; logistics (inbound and outbound) supplier.

Each of the subcontractors prepares operational plans (for day or shift) of his activity based on the supply orders given by the contractor. In some of the models (products) of contract furniture the subcontractors develop on their own the end product and transfer it to the outbound logistics supplier. When this is impossible the end products are assembled in final assembly and shipment area of teams, composed of elected operators of the engaged suppliers. In some contracts there are clauses for promulgation of the delivered in the past contract furniture. In these cases the contractor plans the activity of the inbound logistics supplier to deliver following a precise plan the furniture to be promulgated (reconstruction of components and change of valances) and to direct them towards the disassembly area. On Disassembly area the teams, composed of elected collaborators take the furniture to pieces and send the parts to the relevant subcontractors, who perform the renovation according to the contractor's plan.

7. METHOD FOR DECENTRALIZED PREPARING OF THE ACTIVITY PLAN

The specific characteristic of the suggested method is that the planning process of the activity subcontracting park is decomposed to several independent stages:

- Calculation of the production capacity for completion of the received by the contractor orders list (master schedule);
- Distribution of the master schedule in time (planning and scheduling);
- Detailed operational scheduling.

The evaluating team of the required capacity is characterized with the fact that based on the received by the contractor orders list; it gives an evaluation whether the implementation of the master schedule is possible in practice having in mind the time fund of the distributed manufacturing system. At this stage no schedules are made but just a brief estimation if the available time fund of the manufacturing system may support the load received by the contractor. The estimation might be "impossible" or certain percent ranging from 0 to 100%. This estimation will precise the planning of the next stages on the basis of balancing of the distributed manufacturing system (Capacity Planning).

As a result of this estimation emerges the possibility for collecting of generalized indexes for the exploitation of the technological equipment in manufacturing systems for the different sub contactors and histograms for the load of each equipment unit (machine, work place, etc.) – daily shift basis coefficients of exploitation.

At the stage of distribution of the master schedule (planning and scheduling) are resolved the problems from the previous stage but the requirement is clear knowledge of the preliminary load of the distributed manufacturing system. The tasks at this stage are resolved automatically by ERP system of the contractor, which completely performs the planning.

The whole process of distribution of the master schedule is decentralized, which means that different systems resolve different planning tasks. The highest level in the ERP system of the contractor resolves the strategic tasks connected with management of the resources of the subcontracting park, e.g. aggregate planning.

At the lower level - production unit (manufacturing system of subcontractor), through decomposing of the developed by the ERP system aggregate plan, may be performed distribution of the customer orders to the production sites (subcontractors), e.g. how many and what kind of sets of components and assembly units should be manufactured for the scheduled period.

Within the manufacturing systems of the subcontractors the activity of manufacturing of components and assembly units is implemented on specific production unit (lines, cells, work centers), for which should be counted factors like: adjustments; technical maintenance; repairs; failures; transport and storage operations; number of operators, maintenance staff, etc. These tasks are resolved by the manufacturing execution system of the subcontracting park (MES system), which implements this detailed operative scheduling.

Production units (lines, cells, work centers), implement specific technological processes, which are also subject to automation in their control and management aspect. This task is resolved by Supervisory

Control And Data Acquisition systems (SCADA systems).

For guaranteeing of the efficiency of the suggested system for decentralized schedules preparing are provided two dispatching loops:

- external loop (L1), which monitors the capability for implementation of certain volume of activities in the existing system of time constraints for the scheduled period and terms for manufacturing of specific items of the master schedule;
- internal loop (L2), which monitors the required corrections in the current schedule, due to the emerged variations (defects, wastage, failures, stand by, etc.).

An advantage of the suggested decentralized method for production planning is that the comparatively difficult from mathematical standpoint combinatory problems for generating manufacturing schedules, which the majority of ERP systems can't resolve successfully, here are resolved by two separate systems – ERP and MES systems.

This approach is extremely effective in distributed manufacturing systems composed by considerable number of production units, located in various production sites. In this specific case for manufacturing systems of the seven subcontractors the number of production units exceeds 90.

The delegation of part of the planning tasks to MES system helps for tracking all the changes emerging in the production systems of the subcontractors and allows immediate corrections according to the plans.

When detailed operational scheduling is performed, the suggested system resolves two main tasks:

- calculating the production schedule (Production Scheduling);
- grouping of components, assembly units and manufacturing equipment (Group Technology).

In the procedure of grouping of components, assembly units and manufacturing equipment within the manufacturing system for each subcontractor system are developed optimum route operations. It is common for similar components, assembly units and groups of interchangeable production units (machineries). The schedule is designed precisely for these optimum route operations.

In these conditions it is much easier and effective to resolve the second task– preparation of a detailed production schedule.

Designed in this manner, the production schedules may be easily implemented.

At a further stage, the system for decentralized production planning may be upgraded, by applying the principles of interactive generation of production schedules.

Therefore, we suggest that the task for automatic distribution of the master schedule is resolved by the third specialized system, for advanced planning and scheduling (APS system). The specificities of the distributed manufacturing of contract furniture requires the development of entirely new method for detailed production planning, which should be applied to the suggested development of a system for production planning. This generally new method is required because, the hybrid production system for manufacturing and remanufacturing of products is considerably different from the traditional manufacturing, for which are designed the offered on the market advanced planning and scheduling systems (APS systems).

Even though the suggested APS systems can't create precise production schedules and they don't use optimization criteria on the level of production site (production system of the subcontractor), they are a very suitable solution at low scale batch production and great variety of manufactured products. This is the case of remanufacturing of exploited contract furniture. In these conditions it Is not required precise production scheduling, but a simple answer to the question what is the required time for a manufacturing system to manufacture a specific portfolio of products, counting the due dates of supply, of details and units in the whole subcontracting park.

The planning accuracy of the suggested APS system will be sufficient for the operations planning of all production sites (subcontractors) of the subcontracting park for the scheduled period, because due to its integrity it will count the conditions for sequence of the operations (required by the logistics of the technological processes). Afterwards the production schedule will be decomposed at the level of production units for each of the production systems of the subcontractors and for its feasibility will take care the common for the subcontracting park MES system (Fig. 3) .

In the suggested advanced system for operative production control is envisaged that the production schedule is designed interactively. First, the ERP system of the subcontracting park will develop an aggregate production plan, which afterwards will be precisely calculated by APS system and transformed in detailed production schedule for the whole subcontracting park. This detailed production schedule will be decomposed and calculated more precisely by MES system according to the specificities of the manufacturing system of each subcontractor.

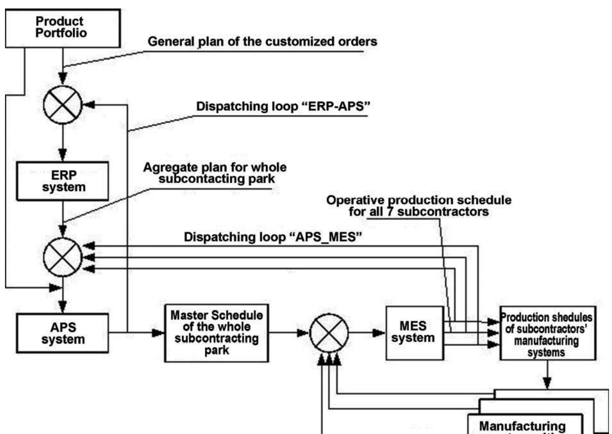

Fig. 3 *Scheme of the suggested advanced system for production management*

By applying the suggested advanced system for each work center might be generated detailed work orders with determined moments for the start and finish of each operation. Work orders will correspond to the optimum plan for accomplishment of the manufacturing activity.

A significant advantage of the suggested advanced system is that the developed by the MES system detailed operative production schedules, will be constantly monitored. This will be achieved by the dispatching module of the MES system. With this module will operate the dispatchers of the production systems of each subcontractor. Their main task will be the registration of all events occurring in the manufacturing system – points of the action, points of terminating the processing of components batch and assembly units; equipment failures; random haste and delays during the different technological processes.

The informing of the dispatchers for emerged events may be performed in different ways – going through the work centers; messages from the operators of the work centers. For the automation of the process it is suggested to use supervisory control and data acquisition systems (SCADA), which should be applied to the manufacturing systems of each of the subcontractors. The data for the condition of the work centers will be delivered by the control systems of the CNC equipment, by programmable logical controllers and by reading devices to radio frequency identification stickers (RFID), bar code stickers or QR stickers. Some of the events will be logged manually by the dispatchers in the MES system, on the basis of all received details by supervisors and operators of the current condition of the manufacturing system.

In certain intervals the MES system will automatically analyze the data received from the dispatchers' terminals. If it encounters significant deviation of the planned values (terms, operations due dates etc.), the system will inform the relevant dispatcher of the specific subcontractor and will suggest one of the following options:

- Temporary substitution of the due dates of some operations;
- Second calculation of the production schedule (for more significant deviations);
- Stay of the operations of one or more work centers;
- Change in the priorities for start of the production of one or more batches of components and assembly units.

After the dispatcher takes decision and the corrected production schedule begins to implemented as a system the work centers affected by the corrections should be precisely mentioned.

8. CONCLUSION

The analysis suggested in this work demonstrates that remanufacturing is a perspective method for extending the life of contract manufacturing. It proved the considerable benefits for protecting the environment and for increasing of the competitiveness of the furniture enterprises in the conditions of economic crisis. In spite of the numerous advantages of the remanufacturing strategy, it engenders many organizational problems and complicates the operation planning and control in manufacturing compared to the traditional manufacturing processes. Therefore, the suggested idea for remanufacturing park is a possible option for resolving these problems.

In future the efforts should continue in direction of design and optimization of systems for management of remanufacturing park.

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