Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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DAAAM Symposium

ADAPTIVE CONTROL SYSTEMS FOR RESPONSIVE FACTORIES

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Abstract: *Shorter product lifecycles, an exponential increase in product variants, and an increasing trend towards customer-oriented lot-size 1 production raise the need for new production planning and production control models. To be successful, manufacturing organizations and business processes have to be transformable to cope with these turbulent environmental changes. In the paper we present how the manufacturing system can be organized to respond to disturbances and changes in production environment.*
Key words: *adaptiveness, reconfiguration, complexity, trends*

1. INTRODUCTION

Global increasing competition forces enterprises to continually improve the quality and economy of their products, services and processes. It is no longer sufficient to produce cheaply. In the long term, enterprises have to be capable of responding flexibly and quickly, accurately and intelligently to current market trends and customer needs and demands. To allow this to happen, there is a basic requirement for flexibility and versatility that goes well beyond the internal capabilities of a company. Flexibility includes changes in the machines, the control algorithms and structure, the system software, and the production system arrangement to adapt the system's functionality and capacity to market demands.

Shorter product lifecycles, reduced time-to-market, volatile markets, an enormous increase in product variants, an increasing trend towards customer-oriented lot size 1 production, and mass customization raise the need for new production planning and production control models and require new approaches for production lines and intelligent machines to provide stability, sustainability and economy in such production conditions. Reconfiguration, both at machine (physical) and control technology (logical) level is necessary to achieve the flexibility required by these paradigms by technical means. It is important to be agile to react fast to sudden and unpredictable changes with a minimum of risk. Implementation of adaptive production systems should improve the company's productivity by at least 20 % and increase the value added time up to 90 % or more (Caridi & Cavalieri, 2004).

Growing complexity is one of the most significant characteristics of today's manufacturing, which is manifested not only in manufacturing systems, but also in the products to be manufactured, in the processes, and in the company structures. Several complexity measures are known: time-complexity, space-complexity and, for distributed systems, communication-complexity (Monostori & Csaji, 2008).

2. OVERVIEW

Complex adaptive systems (CAS) are especially important for production control research, with the goal to study the structures and dynamics of systems and the question, how the adaptability of systems creates complexity. Control as a whole becomes very difficult due to complex operation sequences and routings of different products. A CAS can be considered as a multi-agent system, where a major part of the environment of any given adaptive agent consists of other adaptive agents. When overloaded, individual agents decompose themselves to increase parallelism, so that response times are shortened and later decomposition requests in such real-time adaptive system disappear (Komma et al., 2007).

Agent-based applications provide a new way of viewing problems and deriving solutions. Compared with centralized systems, agent-based architectures are easier to maintain, modify and extend (Mitrouchev & Brun-Picard, 2007).

A first step to adaptive production systems is the transition from a non-recurring, static planning and operation cycle to a continuous replanning and reconfiguration of work systems, supported by new planning methods and tools (Kuchner & Maerz, 2002).

2.1 Process planning

In process planning intelligent automation systems identify individual requirements with respect to handling and processing. Processing strategies are created autonomously; processes are planned and optimized automatically. Self-programming systems automatically convert the planning results into machine control logic. Intelligent planning means best-possible integration and coordination of information and continual optimization of decision finding strategies. Integration means defining an efficient basis for decision making. Intelligent optimization procedures guarantee planning ability and planning stability even in highly dynamic conditions. They support production planning by automated sequence planning or batch size optimization. Automation of complex workflows often means emulating human cognitive abilities in software. Developments of this kind are typically very complex and time-consuming. New artificial intelligence methods make it possible for machines to learn directly from humans and to make decisions autonomously.

2.2 Short-term production planning

Short-term production planning includes scheduling, lot size optimisation, and dispatching of orders within a defined, task-specific planning horizon, taking framework conditions such as the availability of resources and materials, tooling sequences and deadlines into account, and optimising with respect to competing individual objectives. This means taking different cost factors, such as carrying costs, tooling costs, cost of delays in delivery, resource costs, etc. into consideration when assessing fitness and thus effecting optimisation. Adaptive, reconfigurable production systems program themselves within a couple of minutes, instead of taking hours or even days. Also the adaptive control can make a production system to rapidly respond to disturbances and changes encountered during the production of a specific product. Adaptive production systems can modify their own production rules by adding new, deleting old or changing existing rules. Possible adaptive mechanisms include: alternative resources, alternative processes, increase in production capacity and changes in task priority.

2.3 Layout

To ensure the flexibility, a manufacturing system may be organized in form of job shops or FMSs. They share a common in that they are controlled as whole and from resource management point of view. Since manufacturing in agile manufacturing paradigm is usually customer driven, a manufacturing system may produce several products at the same time (Jiang et al., 2000).

Generally it is recommended to organize the manufacturing resources structure in a hybrid layout type, combining the advantages (flexibility, productivity etc.) of both basic (functional and product-oriented) layout structures. For assembly applications the use of autonomous assembly robot stations and mobile transport robots seems the most promising solution.

3. CONCEPTS OF PROBLEM-SOLVING

Manufacturing systems should be organized into several dynamic production systems logically according to workflow of individual products. Systems should take heterarchical control structure rather than hierarchical one adopted in dynamic environments. The advantage of this structure is in fast response to disturbance, which is demanded by adaptive control, and reduced software complexity. It allows direct access among manufacturing resources in a system. No guarantee of global optimization is the main disadvantage of heterarchical control structure, but this can be cleared by the coordination among the controllers using adaptive agents, which are responsible for scheduling and controlling toward optimization. The inputs to the adaptive controller are the product-production structure (sequence and estimated time duration of processes, required resources) and required lead time of a product. The resource planner allocates all required resources and real time scheduler generates a production schedule. Following this schedule, the dispatcher releases control orders to controllers of resources to carry out the production. The product and production resource states are monitored and based on this states the simulator emulates the production to estimate the actual lead time. If the estimated lead time is beyond the time allowed, the system is rescheduled in real time, and the system is then controlled by following the updated production schedule. So, scheduler, dispatcher, system-monitor and simulator form a closed control loop. Adaptive mechanisms include the addition of production resources, modifications of routings, adoption of alternative processes and production resources, decomposition methods to make sub-tasks which can be dealt in parallel or in overlapping mode etc.

Current research areas in the initial phase (with active participation of industrial partners) including specific limitations within manufacturing industry are listed below:

- Concept of adaptive control system for intelligent factory.
- Automated planning of resources' layout structure.
- Automated process planning and robot programming.
- Application of agent-based adaptive control systems.
- Application of neuron-based adaptive control systems.
- Intelligent software systems for process modelling and information architectures.
- Evolutionary strategies in system optimization.
- Data-driven generic simulation models and modules.
- Simulation-based planning and optimization.
- Stochastic elements in planning and evaluation of results.
- Modularity, reusability, and maintainability of manufacturing control software.
- Open, embedded, real-time capable runtime environments for reconfigurable automation and control systems.
- Distributed control systems based on IEC 61499 (open standard for distributed control and automation).

The research shows that it is very hard to switch from the prototype (or pilot) level to the real application level. Development in details (Fig. 1) and implementation of self-adaptive production systems is a vision for the near future.

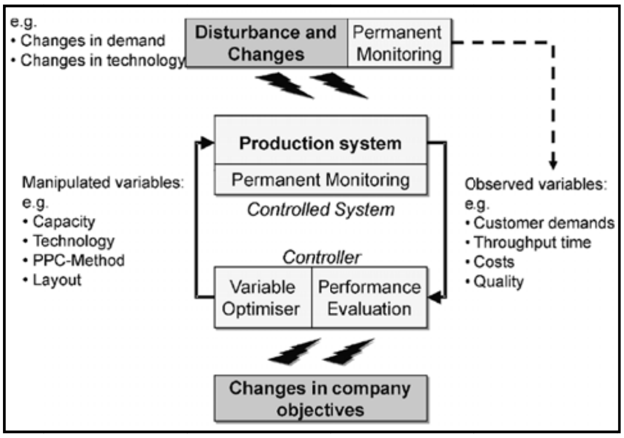

Fig. 1. Control loop of a self-adaptive production system

4. CONCLUSION

In the long term, production and manufacturing companies will only be able to survive in the face of increasing globalisation if they can react flexibly and quickly to changing customer and market demands.

Agent-based modelling and simulation of manufacturing system provides higher flexibility for real-time decision making due to the autonomous nature of agents in the system. The distributed intelligent control with agent-based approach provides the advantages of adaptability, ease of upgradeability and maintenance and emergent behaviour. The most important benefits are:

- Improved productivity, optimized investments.
- Reduction of transaction costs (using information and communication technology).
- Automated production in batch sizes of 1 or more.
- Automation for customizing and prototype building.
- Fast, low-risk, product introduction and product changes.
- Reengineering and extension of production lines without downtime.

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