Building Blocks for Adaptable Factory Systems

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ABSTRACT

Markets are becoming increasingly dynamical and unpredictable. Trends such as the shortening of the product life cycle, individualization of customer requirements and globalization, which includes an adaptation to international markets and standards, can be observed. In result, demands for adaptable factory systems are increasingly addressed towards industrial engineering. The department of Factory Planning and Factory Management of Chemnitz University of Technology has proven its competences on this subject by developing approaches like Component-based Planning, PLUG+PRODUCE, High Performance Ramp-up or Competence-Cell-based Production Networks. These competences are now used in the project "Building Blocks for Adaptable Factory Systems". In this project, partial factory systems are basically researched and transferred to industrial practice. The objective is to achieve an adaptability which meets the particular requirements of the planning situation. This is tried to be met by the elaboration of change-drivers like universality, mobility, scalability, modularity and compatibility. Therefore, the drivers’ working principles have to be understood and made accessible. Concepts, procedures and methods for the design of future adaptable factory systems have to be developed. The central component of the set of building blocks is a manufacturing complex connected to the logistics system of an Experimental and Digital Factory by custom-built interfaces. The adaptability of the system is supported among others by tools for the digital factory, innovative identification and positioning systems, concepts for the supply of material and the self-controlling of logistical objects, as well as man-machine-interfaces. The paper will give an overview about the approach of Building Blocks for Adaptable Factory Systems. The relevant terms are defined and underlying concepts are presented. Concepts for central controlling as well as distributed controlling with RFID are introduced. First building blocks will be introduced. Deployed tools and equipment are discussed. Approaches for an effective energy management are explained.

1. INTRODUCTION

Trends such as the reduction of product life cycles, individualization of customer demands and globalization lead to increasingly dynamical and incalculable markets. In result, the design of adaptable factory structures is required from factory planning.

The department of factory planning and factory management at the institute of industrial sciences and factory systems of Chemnitz University of Technology has proven its extensive competence in this field (e.g. Building Block Development [1], Component-based Planning [2], PLUG+PRODUCE [3], High Performance Ramp-Up (HIPER) [4], Collaborative Research Center (CRC) 457 [5], Project Cluster 196 [6]). The results of this research are now consistently implemented in the project “Building Blocks for Adaptable Factory Systems”. Further basic research and a transfer to industrial practice will be realized for selected factory subsystems.

In this paper, a brief discussion of the basic concept will be provided in section 2. In section 3 the concept of building blocks for adaptable factory systems will be presented. The modules of the overall architecture will be discussed in more detail in section 4.

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2. BASICS

2.1 ADAPTABILITY

There are different terms used for the concept which is here called adaptability. Many authors use “changeability” while “mutability” is used by others. “Transformability” is used rather seldom. The difference in terms is mainly due to the fact that the concept was discussed first in German publications [7]. Hereby, adaptability is the ability of a production system to change its structure actively on all levels at low costs in response to external or internal triggers (following [8]). The concept also must not be confused with that of flexibility. The view in Systems Engineering, that flexibility is the ability to change the state and adaptability is only the ability to change within a state [9] is not adopted here. Eventually it was decided to use adaptability since the word emphasizes the positive direction of the change and the response to external influences.

Different types and dimensions of adaptability are distinguished, namely spatial adaptability, temporal adaptability, structural adaptability and technical adaptability [10].

In an object oriented manner adaptability can also be connected to products and services, technologies and processes as well as to production systems (man, technology, organization);

- Adaptability with regard to products/services to be generated,
- Adaptability with regard to functions and processes which can be realized,
- Adaptability with regard to elements and structures of the factory.

There are change-drivers which increase the adaptability of a system if they have been implemented in the design phase. Change-drivers for factory systems are universality, mobility, scalability, modularity and compatibility. Their working principles need to be understood and made countable in order to develop appropriate concepts and methods for future adaptable factory systems. At the moment this is a subject for much further research.

2.2 EXPERIMENTAL AND DIGITAL FACTORY

The VDI (Association of German Engineers) defines the Digital Factory as “a comprehensive network of digital models, methods and tools, including simulation and 3D/VR visualization which are integrated through continuous data management.” [11] A holistic planning of the product and the respective production system through their whole lifecycle is pursued. The Digital Factory is a vital instrument for increasing adaptability. It is not only useful for planning new facilities, but also for fast improving existing factories by applying planning measures in response to a changing environment. Adaptations of the factory system can be quickly and inexpensively evaluated in the digital model and can readily be implemented [12].

At the department of factory planning and factory management of Chemnitz University of Technology the concept of the Digital Factory is implemented in connection with a model factory. Thus, the configuration, which is contained in the digital model, materializes in the real experimental factory. This Experimental and Digital Factory (EDF) is used for different research projects which cover basic research as well as applied research with industrial companies, which are enabled to present their latest technologies. On the same scale the EDF is used for the education of students.

2.3 COMPONENT-BASED PLANNING

The general idea of the method of Component-based Planning (figure 1) is that catalogues of components are not only provided for the object domain/production process (object components) but also for the method domain/planning process (planning components). A standardization of the planning process and the production process as well as a reduction of the complexity can be achieved by the stringent application of the building block principle. Hence, through the use of proven and tested components, a rationalization and acceleration of the planning process is intended. At the same time quality is increased.

Components of the planning process (planning components) are standardized units of the process of transformation of information. These components mainly integrate the planning functions, the relevant planning methods and competences as well as input and output information. In contrast, components of the production process (object components) refer rather to physical objects as well as the necessary competences. There are predefined procedures for the identification, selection and coupling of building blocks amongst others. Generated
Building blocks can be used for the Component-based Planning of production plants on the base of these procedures. They can be combined to obtain planning processes as well as production processes for production plants. The experiences from the application of the building blocks are used to improve the building blocks. That leads to the optimization of the building blocks, which at the same time store the acquired knowledge.

Therefore, not only the particular parts of factory equipment (object components of the Component-based Planning), but also the interdependent steps of the planning process (planning components of Component-based Planning) itself are cataloged in a tool for the administration of the building blocks, the component configurator (figure 1). In addition, it must be possible to parameterize and modify both types of components in a comprehensive way. Components of lower order should be possibly subsumed to components of higher order. The configuration of the planning process should be done graphically. Its implementation should be guided by a planning manual. The visualization should provide a realistic mapping of the factory in an easy way. In addition to technical considerations, issues of work science (e.g. working environments, interactions of humans) should also be addressed.

Figure 1: Method of Component-based Planning (Principle) with component management processes

3. CONCEPT OF BUILDING BLOCKS FOR ADAPTABLE FACTORY SYSTEMS

3.1 OBJECTIVES

Building blocks for adaptable factory systems will make it possible to investigate almost any factory configuration (e.g. order driven, flexible layouts of machines (figure 3) in connection with production and logistics concepts for optimal lot sizes such as one-piece-flow) prototypically and emulate it close to reality. Conclusions about the behavior of the factory and its components shall be drawn in anticipation of an actual realization. Innovative concepts, technologies and solutions shall be evaluated with regard to their suitability for industrial practice. New and further developments of components of factories, such as energy-saving solutions for materials handling technology and their interaction with other components shall be tested. Last but not least, the interaction and the behavior of humans in the factory as well as their acceptance of technical innovations will be researched.

In addition to adaptability, the following trends and research areas of industrial science will be covered with the factory building blocks:

- Demography, group work and working environment
- Information and communication, man-machine interfaces
- Handling and supply concepts
- Energy efficiency
• Unity of planning and operation of a factory
• Digital factory, further development of methods and tools for factory planning.

According to the approach of the Digital Factory, the research will be carried out on one hand virtually at the computer and on the other hand in a small model factory in reality. In result the factory building blocks, which enhance and complete the existing Experimental and Digital Factory (EDF), consist of the components Digital Center (DC) and Experimental Center (EC). The components can be combined via defined interfaces.

3.2 PRODUCT

For evaluating the building blocks on a laboratory scale a line of products had to be chosen. The reference product is an engine cylinder block which can consist of disks with varying thickness. The high product variety, which is typical for modern production, is simulated by applying different colors to the different disks. The cylinder block rests on a base plate. The disks are attached by bolts. Up to six disks or blocks can be kept on a carrier.

Different types of master production schedules can be mapped. The focus will be on single piece and small batch production which becomes possible through the product variety. The simplicity of the product allows however also to consider medium batch production.

3.3 ARCHITECTURE OF THE BUILDING BLOCKS

Following the underlying paradigm, the building blocks for adaptable factory systems have a modular structure. The following modules are planned to be integrated in the building blocks (figure 2);

• Components of the digital center (DC)
  o Modules for planning/visualization (component configurator, visualization (VR, interaction))

• Components of the experimental center (EC)
  o Machining modules (manufacturing/assembly modules (4+1), test module)
  o Material flow modules (handling module (gantry robot), transport module)
  o Information flow modules (control center, control, interface modules)
  o Energy flow modules (supply, energy management modules)

Figure 2 illustrates the concept of the integration of building blocks for adaptable factory systems in the EDF.

The planning and visualization modules are integrated in the Digital Center (room D19). The machining modules as well as the material, information and energy flow modules are integrated in the experimental center (rooms D17 and D18).

3.4 CENTRAL OR AUTONOMOUS CONTROL

Both, central and autonomous control will be provided in the EDF. A procedure is defined for switching between the modes of control in order to avoid inconsistencies in the data of the EDF.

Central control is managed by a production control center as customized part of a standard ERP-software package (MS Dynamics AX 2009). It creates the production and logistics orders and passes them with the necessary information to the numerical controls of the machining components and the logistical pilot control center.

Autonomous control is managed through information which travels with the products in the form of RFID-tags. This information includes the steps of production of the product together with the respective machining components. The data is written to the RFID's of the parts and the final products before they enter the system. The RFID-tags are read at the machining components and certain points of the logistics network. The data is made available to the control of the machining components and the logistical pilot control center by a middleware. The start of the production and the transfer is then negotiated with the machining components and the logistical pilot control center. However, the ERP software is informed about the state of the product.
4. COMPONENTS OF THE ADAPTABLE BUILDING BLOCKS FOR FACTORY SYSTEMS

4.1 PLANNING AND VISUALIZATION MODULES

The planning and visualization modules component configurator and visualization base on concepts such as Component-based Development [1], PLUG+PRODUCE [3] as well as Component-based Planning [2]. The modules ensure that the designed factory can be planned and displayed efficiently, rapidly and in high quality on a computer. The optimized components are modeled for different tools, besides visualization tools particularly for simulation and business process reengineering. Especially the planning and visualization tool visTABLE [13, 14] is deployed for mapping the layout of the factory and evaluating possible changes virtually. It will be upgraded to recent technological developments. So a movement of camera and objects through Nintendo’s Wii as interface device will be realized.
4.2 MACHINING MODULES

Four functionally universal manufacturing and assembly modules are the core of the building blocks for factory systems. They can be placed arbitrarily in the layout and are meant to represent the machining equipment of a factory. Figure 3 illustrates two possible layout variants in the EDF (i.e. central positioning under the gantry robot, non central positioning in the free space).

Cell 1 is an assembly cell which is able to stack the disks on the plate and on the bolts to obtain the cylinders. Cell 2 tests the assembled blocks in comparing them to the photography of a master product. Cell 3 simulates processing of single parts while cell 4 provides a manual workplace which can be used to disassemble the cylinder blocks for further use.

Thus it becomes possible to produce different products with different process chains on laboratory scale. The vision is to copy the EDF as a factory model (e.g. with LEGO building blocks).

In addition an automatic assembly machine installed in the EDF (as fifth cell), as well as an existing test station should be integrated in the overall concept. The automatic assembly machine illustrates control, disassembly and packing processes, while the test station illustrates control and test processes.

4.3 MATERIAL FLOW MODULES

Material flow modules have to connect the manufacturing and assembly modules as well as already existing components such as the high-rack storage in the material flow technical aspect. Therefore, an automatic guided vehicle (AGV) and a gantry robot are integrated in the building blocks for adaptable factory systems. The AGV can recognize the cells which can be arbitrarily arranged in non central configurations, at their position by means of its controlling unit and supply or collect material (figure 3). The gantry can handle the material supply of the four cells in a central configuration. It can as well be used for complex storage and commissioning assignments (figure 3). Additional handling equipment supports amongst others the handling to manufacturing and assembly modules as well as the implementation of supply concepts.

The equipment can be controlled both automatically as well as manually. The AGV can reach almost every position in the factory. Thus, machining equipment can be moved without expensive modifications in the material flow equipment.

4.4 INFORMATION FLOW MODULES

The information flow modules ensure the interconnection of the manufacturing/assembly, material and energy flow as well as the planning and visualization modules in the information aspect. This includes the architecture of the control center module, the installation of additional components as part of the control module as well as the incorporation of innovative identification systems (e.g. RFID) in the machining and material flow modules (among others definite identification and routing of the load units). Control systems of additional equipment can be incorporated. An integrated data flow is aimed at by connecting tools for design with tools for execution.

The integration of factory planning tools to the operative control components is realized by deploying the Net Planning Assistant (NPA) [15, 16]. The data exchange uses the central production database (PDB) and the uniform interface concept. Particularly interfaces to the control centers are under development.

The technical basis for the information exchange between all components is guaranteed by Ethernet connections and WLAN, where highest flexibility is needed. The amount and route of the information flow depends on the selected control strategy (see subsection 3.3).

4.5 ENERGY FLOW MODULES

A supply module, which was designed as an overhead media line, has to assure the flexible discharging of energy by the mobile manufacturing and assembly cells as well as the flexible logistics equipment (roller conveyor segments). Particularly the media electrical energy and compressed air should be provided area-wide.
An energy management module provides the elicitation of energy-related information from the machining, material flow and energy flow modules. Inversely, a well-directed simulation and regulation of energy-relevant parameters are enabled by the energy management module. The energy management control will be incorporated in the control module. It will help to investigate the interdependencies between adaptability and energy efficiency as part of the building blocks for adaptable factory systems.

5. SUMMARY

Building blocks for adaptable factory systems, is a concept which shows a way for factory planners to meet the demand for more adaptability in modern production systems. It has been implemented at an Experimental and Digital Factory at the Department of Factory Planning and Factory Management of Chemnitz University of Technology. It was shown that all types of flow in a factory are covered.

Primarily, the building blocks for adaptive factory systems serve as a laboratory for basic research about adaptability. However, the research results should be transferred to industrial practice at an early stage. Hence, the factory building blocks can serve as a test environment for innovative plant producers.
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