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Agent-based manufacturing execution systems for short-series production scheduling

Rafal Cupek[a,*], Adam Ziebinski[a], Lukasz Huczala[a], Huseyin Erdogan[b]

[a] Silesian University of Technology, Institute of Informatics, Gliwice, Poland
[b] Conti Temic microelectronic GmbH, Ingolstadt, Germany

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ABSTRACT

This paper presents the architecture of Agent-based Manufacturing Execution Systems dedicated for short-series production support. The functional models are based on the ANSI/ISA-95 (IEC/ISO 62264) standard. The workflow and information exchange for Manufacturing Operations Management are defined by ISA 95 and implemented under a dynamic Agent-based environment. The proposed system is organised as a fully heterarchical architecture, without a central administration or system orchestrators. Unlike most of the existing agent software that are based on Java, the proposed solution is based on Microsoft's Model-View-Controller and was created under the ASP.NET technology. Holons, which collect information from the real production system, are a Cyber Physical part of the application. Agents process information using Internet services that are available for human users and for the other agents as well. The proposed approach has been verified on the use case of the system that was created to support the production of electronic devices in the Prototyping Department of Continental Ingolstadt. The system model, applied communication mechanisms and examples of agents are presented in this paper. The research part of this paper is focussed on simulation-based planning for a short-series production schedule. The simulation results can be used to support the decision-making process.

1. Introduction

Nowadays, control systems provide very detailed information about the underlying production process. This information is further used by Business Intelligence systems, which are localised on the Enterprise level. Moreover, decisions taken on the business level have to be executed by control systems. Manufacturing Execution Systems (MES) are service-oriented interfaces that connect the world of business operations with the world of production. The classical MES are defined by a static hierarchy of services and data structures, which makes them very difficult to modify. The change of the production model from mass manufacturing to customised manufacturing and short-series production presents new challenges to MES [1]. The emergence of the concept of Cyber Physical Systems (CPS) enforces changes in the architecture of MES. The automation pyramid is no longer a canon in industrial IT systems. CPS are formed by networks of distributed operating entities providing the production process. MES must follow this idea through new architectural solutions. A new approach to the architecture of MES is also indispensable to support agile manufacturing. The authors propose a heterarchical MES architecture based on a multi-agent system that is designed to work inside and cooperate with CPS.

In the case of mass production, there was enough time to find the best scenario for the production process in terms of the best production technology and manufacturing operations schedule as well as to find the optimal setup parameters for particular production devices. In addition, the manual actions performed by operators were more stable and the final results more repeatable. In the case of short series manufacturing, the production technology is often changed, production tools have to be adjusted to specific products and the process organisation must follow these changes in order to avoid or reduce losses resulting from non-productive time gaps [2]. Moreover, time-to-market and product development time have become critical aspects of innovation processes. In such a case, the benefits from MES that support manufacturing can be far more important for enterprises than in the case of mass production. CPS improve the availability of information about the progress of the production process that is required by MES. On the other hand, MES can help CPS in the

* Corresponding author.
E-mail address: rcupek@polsl.pl (R. Cupek).

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planning and the organisation of the manufacturing. A proper cooperation between MES and the CPS is particularly important in the case of short series manufacturing.

Research results show that trade-offs are made not only between time, quality and expense but also that trade-offs relate to when additional development expenses are incurred, including cross-functional integration (both internal and external) that substantially impacts on product profitability through a mix of direct and mediated effects [3]. Such integration cannot be reached in an effective way with MES support. The above-mentioned factors mean that Manufacturing Execution Systems should follow the changes in manufacturing. MES should no longer be a closed, fixed IT software, but must be created as flexible and open sets of services that interact with the physical production system. Contemporary MES should follow real production and should be self-adaptive in order to support changes in short series manufacturing. The authors propose to improve MES adaptability by changing its architecture from hierarchical to heterarchical software based on holons and agents.

Cyber Physical Systems are places in which the embedded world meets the Internet world [4]. They deploy embedded cyber capabilities and join them with the physical world, including humans, infrastructure and platforms, which transform interactions with the physical world. In the case of MES dedicated for short-series production, there are also different kinds of actors. Human users such as production managers, the staff involved in production optimisation, the logistic team or quality managers are interested in fast and precise information about production progress, realisation of orders and possible production problems. Other actors are production facilities such as machinery and equipment, which need the information necessary for the effective realisation of the production process and the proper validation of the created products. The products themselves are also active participants in the system since they collect valuable information about the actual production parameters that can affect product utilisation and its future development.

CPSs are glued by web services that are available via the Internet. Cyber Physical Systems have the ability to interact with and expand the capabilities of the physical world through computation, communication and control. They are key enablers for future technology developments [5]. Although some MES functionalities are realised internally, some services need to interact with suppliers and customers and have to be available externally. Such an interaction is especially important in the case of short-series production that needs closer cooperation between suppliers, producers and consumers since the production chain must be more flexible than is the case in mass production. The proposed MES architecture is based on Internet services and binds them with CPS to support both the production and later the use of a product. This paper focuses on the new opportunities and research challenges related to agent-based MES architecture. The authors propose agent-based architecture for flexible and heterarchical MES. The proposed MES architecture is composed of agents that offer and execute virtual services and holons, which are physical process interfaces that ensure the materialisation of services. Together they build a bridge between Cyber Physical and Manufacturing Execution Systems.

The novelty of the presented approach is the new model of MES that are based on a triple-layer heterarchical network of agents that perform the required services and join the physical production environment with high-level decisional systems. The internal layer of this model is close to the physical part of the system and reflects the requirements of the products and production processes. It ensures links to the production devices by means of holons. The middleware represents the dependencies between processes and services. The outer layer forms an external interface to other systems and human users. Such an approach is more flexible and more resistant to implementation errors. Each order is under the care of autonomous agents that support the human participants from one side and represents them in the cyber world. The authors present an activity model of the proposed system. In order to facilitate its application, the model complies with the third part of ANSI/ISA-95 (IEC/ISO 62264-3) [6] standard. The proposed MES architecture has been verified practically on the real example of the production system used by the Prototyping Department of Continental Ingolstadt.

The new functional model requires a new approach to system architecture. Since individual orders are executed independently and have different product supervisors, it is very difficult to take arbitrary decisions in the event of conflicts when accessing resources. In the case of the production that is carried out by the Prototyping Department of Continental Ingolstadt, the classical MES models that are used by Conti's other departments cannot be applied. The main obstacle is that the background knowledge of the production staff cannot be dynamically included in the business models that are represented by MES. In the classical solutions, every change in a model requires a reconstruction of the responsible part of the MES software. In the analysed use case, this is not possible due to the number of variants of production – practically every order is considered as another variant of production. In such a case, a central decision support system must be replaced by local support and the central system must be replaced by the appropriate IT architecture. The authors decided to apply an agent/holon-based solution. Such an architecture, which is described in section 3 and illustrated by the use cases in section 4, allows human users of the system to benefit from distributed schedule planning through a simulation of the execution of the production schedule. From another side, the short-series production that is being considered requires many changes in its organisation. Since, there are different possible variants of production, the holon-based model is more flexible and scalable than the central model of the production that is based on a static facility layout.

This paper is organised as follows. Section 2 introduces the related works, including agent-based MES and interfaces between MES and ERP systems. Section 3 presents the proposed architecture of the system. It describes MES activities using the ISA95 models. It also gives some more details about the implemented business models, the architectural models of agents and holons and presents some details of agent–agent and agent-human communication. It also presents some details related to the application of MES for the electronic device prototype production lines. Section 4 focuses on the system application for the simulation of the short-series production carried out by the Prototyping Department of Continental Ingolstadt. The simulation results give some performance metrics of production that can be used for planning manufacturing activities. Finally, section 5 presents the conclusions.

2. Related work

Nowadays, the rapidly changing environment requires rapid changes in manufacturing systems. Industries must adapt their manufacturing systems to maximise their productivity and the profitability of production. Customers increasingly require a shorter time to market. The changes include shorter product life-cycles, increasing requirements for quality, increasing the customisation of products, the faster implementation of advanced technology and optimising the cost of energy. These expanding options affect materials, processes and interfaces to product models and often the resulting products must be produced in a number of variants. In this section, the authors review the