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A conceptual model for developing a smart process control system

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Abstract

Current Manufacturing Execution Systems (MES) are not supporting a full integration into overall processes across the supply chain. Thus, optimization is limited to single areas. The SemI40 project is aimed at developing an integrated concept of Smart Process Control System (SPCS), which enhances the overall agility and productivity. The system, therefore, autonomously acquires and interprets process data to allow product individual optimization and enhancing logistics management. It also provides full traceability across the supply chain in real-time and allows model based process simulation and decision making support. The concept is developed based on requirements elicitation in cooperation with industry partners and combines state-of-the-art technologies with current trends, like vertical integration, big data and machine learning.

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Keywords: Manufacturing execution system; Smart process control; Requirements analysis; Decision support

1. Introduction

Today's manufacturing industry is concentrated on value creation, based on existing production processes and interconnected digital technologies [1]. In modern production companies, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES) and Advanced Planning Systems (APS) are pillars of IT architecture [2]. Nevertheless, digital transformation has reached the manufacturing industry [3], and there are high expectations on Cyber-Physical Production Systems (CPPS) [4]. While its short-term impact is often overestimated, its long-term impact tends to be underestimated [3].

In this paper, we describe a conceptual model for developing a Smart Process Control System (SPCS), which has been developed within the ECSEL JU project SemI40 [5]. It reflects the impact of the current digital transformation on the application of MES in the context of the semi-conductor industry. In chapter 2, we introduce ten MES general functions that are described in VDI standard for MES [6]. We use these functions to structure our requirements analysis in chapter 3. In order to capture requirements from five semi-conductor companies, we have applied methods of requirements engineering [7] and value stream mapping [8, 9, 10]. In chapter 4, we use the results to create the conceptual model, including a conceptual design of a Decision Support System (DSS) [11, 12, 13]. Chapter 5 discusses the key findings, limitations, applicability and transferability of the integrated approach to other industry sectors. Finally, we conclude and present future research work, in which the focus is placed on how our results can be used in the further course of the SemI40 project (cf. chapter 6).

2. Background: MES general functions

A MES aims to plan and manage manufacturing processes in semi- or even in real-time [2]. It guarantees transparency over processes, as well as information and material flows within the supply-chain [6]. The MES acts in addition to ERP systems, which focus on mid- or long-term goals and a higher company level [2]. According to [6], a state-of-the-art MES contains the following functions:

- *Order management* is a central component within a MES. Usually, an order is the trigger for activities in manufacturing. It contains data that is required for or

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generated during the processing of the order. Various order types reflect the different production steps, like mechanical manufacturing, assembly or maintenance.

- *Detailed scheduling and process control* supports the processing of orders. It considers the availability of resources, like materials, manufacturing systems and work force, and sets them into a chronological order. Besides its focus on planning of manufacturing sequences, it must be able to react on unexpected events in semi- or even in real-time.
- *Equipment management* secures the availability, functionality and reliability of equipment and utilities, and so supports the maintenance process. It can be divided into machines and manual workplaces, tools and supporting equipment, and immaterial operating resources, like Numerical Control (NC) programs.
- *Material management* organizes the appropriate supply and disposal of materials for manufacturing. It especially manages work in process (WIP) goods, e.g. raw materials, semi-finished goods and final products, when they leave an inventory-managed stock.
- *Human resources management* provides the required personnel with the right qualifications and competences. It considers individual data of single persons or groups, like working time, shift plan and time accounts. Besides real-time applications, it is used for capacity planning and historical analysis.
- *Data acquisition* captures and processes event-driven information, like operating and machine data, as well as records of process, quality and personnel. Data transfer and capture can be automated, semi-automatic (e.g. scanner) and/or manual (e.g. typing).
- *Performance analysis* creates control loops to correct operational deviations (short-term) and to optimize and qualify processes (long-term). It enables the creation of reports and Key Performance Indicators (KPIs), comparing expected with real-time data, as well as DSS. It also takes care of process and product improvements, as well as root-cause analysis, enabled by performance and data analysis.
- *Quality management* secures and improves product and process quality. It covers (advanced) quality planning, quality control, gauge and complaint management. It can immediately react to quality issues, which can lead to an adaptation of manufacturing orders or processes.
- *Information management* integrates other MES functions in order to enable the processing of manufacturing processes and their optimization. It distributes and provides required information and can influence and control processes in manufacturing. It enables the allocation of order and resource data to process parameters. It also provides required information for tracking and tracing, as well as specific documents for the corresponding manufacturing step.
- *Energy management* plans, monitors and controls the energy consumption within manufacturing in order to reduce it. It creates transparency and supports an energy-efficient production. Targets can be economically or ecologically, e.g. a reduction of the total energy consumption, an increase of the energy efficiency or energy recovery.

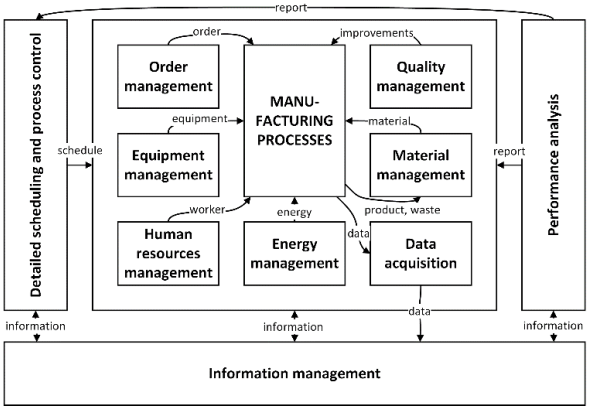

Fig. 1. MES general functions.

Figure 1 shows the correlation between the described MES functions and manufacturing processes. The inner functions interact directly with the processes, whereas the outer ones interact indirectly via the inner functions. The importance of information management will increase in the future with progressing digitalization [3], because it connects all other functions with each other.

3. Requirements from industry partners

In order to create a conceptual model for developing a SPCS, we identified and compiled requirements from five semi-conductor companies. To get a comparable view on the same level of detail and functional category, we designed a questionnaire. The companies were asked to describe their current and their target implementation of the ten general MES functions, listed in chapter 2. The answers have been evaluated by assigning a score, ranging from 0 (no implementation) to 4 (beyond state-of-the art). Afterwards, the results were processed by the requirements engineering team and have been presented in Table 1.

Energy management, human resource management and performance analysis are currently the functions with the lowest score. Mostly, they are implemented using independent software solutions with no automated interface to the MES. In contrast, data acquisition is implemented most sophistically, followed by material management. This is reflecting the typical situation in the semi-conductor industry with high quantities and required knowledge of a single product and related processes. The highest need for a future improvement is on equipment management (+1.8), detailed scheduling and process control (+1.6), as well as human resource management (+1.4). In general, the planned developments are going in the direction of automation, i.e. either creating interfaces between separate tools or integrating them into one.