Analyzing the engineering effort for the commissioning of industrial automation systems

Lars Dürkop[1], Lukasz Wisniewski[1], Sascha Heymann[2], Benedikt Lücke[1] and Jürgen Jasperneite[1,2]

[1]inIT – Institute Industrial IT, Ostwestfalen-Lippe University of Applied Sciences, D-32657 Lemgo, Germany {lars.duerkop, lukasz.wisniewski, benedikt.luecke, juergen.jasperneite}@hs-owl.de
[2]Fraunhofer IOSB-INA Application Center Industrial Automation, D-32657 Lemgo, Germany {sascha.heymann, juergen.jasperneite}@iosb-ina.fraunhofer.de

***Abstract*—In the industrial automation a paradigm shift from centralized, static automation structures to reconfigurabl manufacturing systems (RMS) might be lie ahead. RMS are seen as a key enabler for the required changeability of future production companies since they can reduce the engineering effort needed for the reconfiguratio of existing or the construction of new production systems. However, it is not clear how the companies can benefi from RMS in detail. For example, the reduction of engineering effort cannot be expressed in figu es by today. But such information is necessary to convince the industry of the advantages of the new production principle. Indeed, existing RMS paradigms like Service-Oriented Architectures are rarely used in the practice of automation. The basis for analyzing the advantages of RMS is an analysis of the status quo in the industrial automation. Regarding the engineering effort of current automation systems, this paper will present a case study considering the effort occurring during the commissioning process of a production system constructed by state-of-the-art components. The evaluation of the study can serve as a reference when comparing the engineering effort of RMS with today's systems.

I. INTRODUCTION

Due to shorter product life cycles and the trend to mass customization changeability will be one of the key factors in the competitiveness of manufacturing companies [1]. The term changeability affects all levels of the value chain of an enterprise – from the offered product portfolio down to production tools.

One major factor impacting changeability is the reconfigurability of productions system which can be obtained by the introduction of Reconfigurable Manufacturing Systems (RMSs). These are "designed at the outset for rapid changes in their structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality [...] in response to sudden changes in market or regulatory requirements" [2].

In the RMS context, the design of reconfigurable control systems is the most challenging technically barrier for the widespread use of RMSs in the manufacturing industry [3]. The information and communication technology (ICT) used to realize todays control systems does not sufficiently support reconfiguration and modularization, yet. [4].

Possible architectures for the control of RMSs are a highly relevant topic in the production research for at least 10 years now. The most common approaches discussed for the realization of such control systems are service-oriented architectures and multi agent systems [5]. Both are based on distributed and modular control systems – in contrast to the centralized and static structure of today's automation systems. Indeed, the adaption of existing production systems is a time-consuming and therefore expensive process. This leads to the situation that, in case of product changes, automation systems –at least the control software– are often completely rebuilt from scratch [6]. By using RMS the leadtime for new products can significantly be reduced (see figure 1) – if the mechanical and the control software design supports the re-use of existing components.

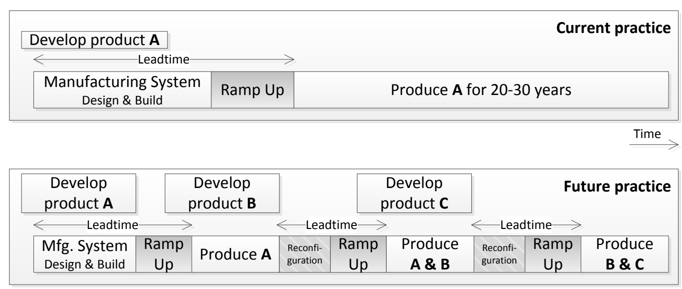

Fig. 1. Reducing of leadtimes by using RMSs [2]

Despite these efforts, the RMS concept is not yet widely used in practice. In [7], the cause for this is seen in technological (insufficient computing power of automation components, insufficient tool support for RMSs, ...) and human (training efforts, hesitation about new technologies, ...) factors. Another reason is that the cost benefits of RMSs, if any, cannot be specified by today: A company does not know in advance whether the initial investment for the changeover to RMSs will be worthwhile. So, the central advantage of RMSs –the reduced amount of time needed for the commissioning of new productions systems or for modifying existing ones– must be expressed in figures. A feasible way to determine this RMS key performance indicator is the comparison of engineering efforts in RMSs and current systems.

Therefore, first of all, the engineering efforts in today's production systems must be quantified and published to obtain a basis for future comparisons. However, existing examinations are not known to the authors. For this reason, the following work will present the results of a case study carried out for

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identifying and measuring the individual engineering activities in the commissioning process of an industrial production system. A subsystem of the SmartFactoryOWL (the assembly line) forms the basis of this study. The factory is structured in a highly modular manner and thus follow the RMS paradigm. Nevertheless, during the construction standard automation components have been used. Therefore, the individual engineering steps for the initial setup of the SmartFactoryOWL's assembly line can be compared with the commissioning of a conventional production system. During the build-up process all activities and their durations have been recorded to obtain a realistic estimation of the engineering efforts. The results are presented in section IV.

This paper is structured as follows: In section II a short overview over the engineering of automation systems is given. The SmartFactoryOWL is introduced in section III. The engineering effort study is evaluated in section IV. The paper ends with a conclusion in section V.

II. Engineering of automation systems

The architecture of an automation system can be divided into different functional layers depicted by the automation pyramid shown in figure 2. All automation components –and the associated engineering steps– can usually be assigned to one of these layers.

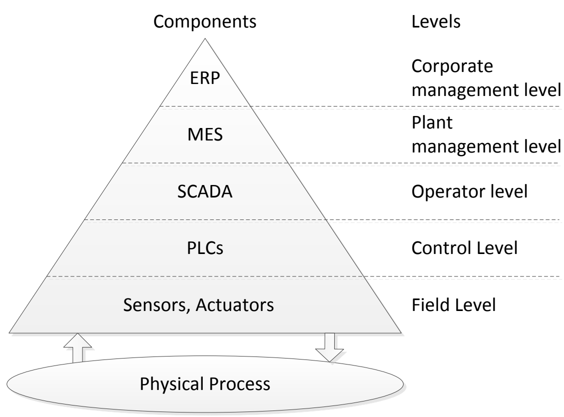

Fig. 2. Automation pyramid

The basis of every automation system is a physical process – i.e. the manufacturing or assembling of a product. This process must be monitored and controlled which is the task of sensors and actuators located at the field level. Here, the engineering effort consists of calibrating the sensors and actuators, if necessary. For example, the thresholds for proximity sensors may be set.

On the control level, Programmable Logic Controllers (PLCs) read sensor values and set actuators values. The underlying control logic must be formulated by the automation engineer – typically, a programming language according to IEC 61131-3 [8] is used for this purpose. Furthermore, the communication between the field level and the PLC has to be configured. Since the closed control loop between sensor, PLC and actuator is often time-critical, dedicated real-time communication technologies are used to link these device. In comparison to networks used in the IT domain, the configuration effort for automation networks is much higher [9]. Besides setting the parameters necessary for the timely transmission of data, the engineer has to connect the communication objects of the control logic (i.e. variables) to the according field devices.

On the operator level, operating and display elements are realized in form of Supervisory Control and Data Acquisition (SCADA) systems. Therefore, graphical user interfaces must be created for all monitored and controlled automation elements. For accessing the relevant data an appropriate exchange protocol between the SCADA system and the PLC, like the OPC technology [10], has to be used.

The higher levels (plant and corporate management level) comprise functions for logistics and business control. Therefore, they do not have a direct influence on the physical process. Manufacturing Execution Systems (MES) control the job execution order of a production line or manage the material feed, for example. The enterprise resource planning (ERP) has similar tasks, but covers the entirety of a company's production. So it handles, among other things, the materials management and initiates ordering processes. Both MES and ERP modules are often realized by using standardized IT software with adaptations to the concrete company and its production processes.

Every automation system consists of components from at least the field and the control level. The upper layers are optional – their frequency of use increases with the complexity of a plant.

III. The SmartFactoryOWL

The SmartFactoryOWL is a research factory operated jointly by the Institute Industrial IT (inIT) of the Ostwestfalen Lippe University of Applied Sciences and Fraunhofer IOSB-INA within the Centrum Industrial IT in Lemgo, Germany. In the context of the "factory of the future", upcoming research topics like adapatibilty, resource efficiency and cognitive human-machine interaction are addressed. The SmartFactory-OWL is used simultaneously as a research and testing lab for scientists and engineers as well as a learning environment for students. Furthermore, small and medium enterprises (SME) can use the factory to test and optimize their production systems with integrated Industry 4.0 technologies and to train their staff.

The SmartFactoryOWL's subsystem considered in this paper –the assembly line shown in figure 3– hast just been completed and consists of three manufacturing cells and a varity of conveyors. The assembly line is already modularized in terms of mechatronis as well as in software. Carriers are used to transport the goods which are equipped with a digital product memory. The product memory consists of an ordernumer, an articelnumer as well as the plan how to build the product. This allows to produce new or different products on the same assembly line at the same time. The first manufacturing cell is equipped with a welding robot. It uses the information from the product memory to dynamically build a part of the product.

The second manufacturing cell is a manual workstation equipped with an assistance system. The worker is assisted

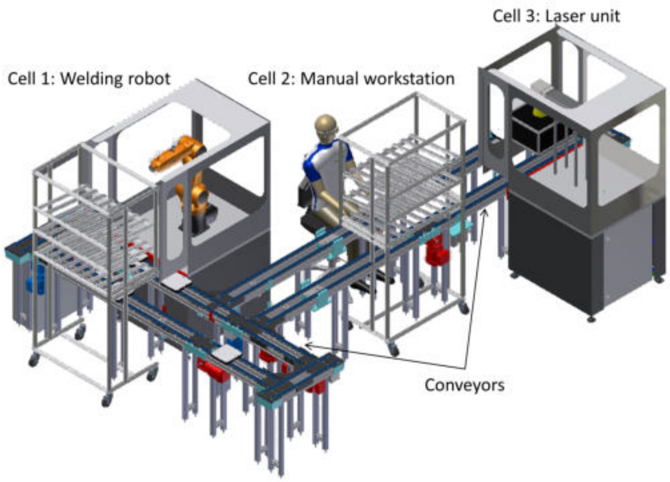

Fig. 3. Assembly line of the SmartFactoryOWL

with augmented reality to produce the second part of the product. The information on how to build the product is directly projected to his field of view using data goggles. Thereby, the training period for new personal or for new products can be reduced.

The third manufacturing cell is a laser unit. This unit is used to customize the product by engraving a logo and an individual text on the product.

Every cell is equipped with it's own PLC, so that future extensions of the assembly line are easier to implement. During the complete construction phase of the assembly line all the individual steps of the process and the required times have been recorded.

IV. Evaluation of the Study

As mentioned in section II, an automation system is a complex infrastructure build upon different hardware and software components which can be grouped according to the five levels of the automation pyramid. In this paper, however, the main focus will be on the two lower levels, namely the control and the field level, which are essential in each automation system. The investigation is based on a survey conducted amongst the control engineers responsible for setting up the assembly line of the SmartFactoryOWL. As a first step of the evaluation all engineering effort incurred during the setup process has been categorized. The resulting classification is shown in figure 4.

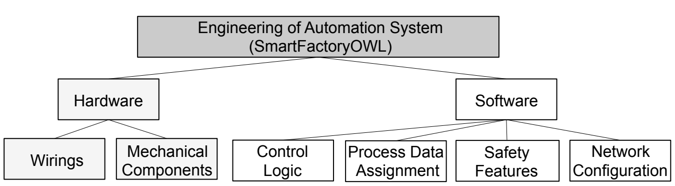

Fig. 4. Identified engineering categories needed for the setup of the SmartFactoryOWL

In a second step, the complexity of the identified engineering categories in terms of time spent, number of tools and materials used and the identification of particularly challenging actions has been performed. The evaluation is split into two subsections which tackles software and hardware related actions performed during the engineering of the SmartFactoryOWL. In both cases the study also identified potential for optimization. A brief description of all these aspects together with suggestions for possible improvements is described in the following subsections, the relative engineering effort in terms of time is shown in figure 5.

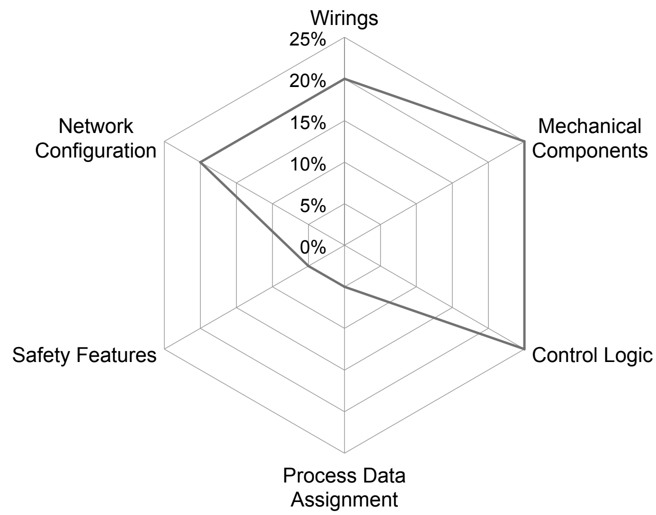

Fig. 5. Engineering efforts summary

A. *Software related actions (Control Level)*

According to the control engineers, the amount of software related actions is about 50 - 60 % of the total time spent for the engineering. In case of Control Logic actions, 7 different engineering tools have been used for programming. This activity includes the control logic implementation for the robot, conveyor belts, laser, the interconnection of the robot control logic with the main PLC, teaching of the robot and integration of the safety logic. The biggest challenge here is to master all the different tools used in this task and to keep tracking the versioning of the software projects – especially, if several engineers are working in parallel. It has been noticed that decentralization of the control logic in terms of smaller control projects would be a great help. The activity Network Configuratio contains actions such as address and name assignment and creation of the (logical) network topology. To perform all these tasks, five different tools from different vendors have been used. Since in the engineering software physical devices are represented by Device Description Files (DDFs), i.e. Generic Station Description (GSD) files in Profinet, it is important that these files match their physical counterparts. This point was also one of the biggest challenges in this task. So, e.g. an automatic download of the appropriate DDF from the Internet would be a great help significantly simplifying this task. Another identified field for improvement is the automatic detection of devices and their connectivity (topology) together with simplified and automatic assignment of addresses and device names. The next important activity is the Process Data Assignment, where mapping between physical input/outputs and control logic variables takes place. Due to good documentation and rather "small" number of sensors and actors this task was not extraordinary challenging. However, in case of large systems with hundreds of sensors, especially of the same type, this task may become a big challenge. Therefore a self description used for expressing the capabilities of sensors and actuators would be a great help simplifying this activity. The activity Safety Featur es implements necessary safety logic, such emergency stop logic or safety functions that stop the robot or the laser when the cell is not safely closed. It was a rather straight forward task, however some initial startup problems delayed this activity.

B. Hardware related actions (Field Level)

The ratio of the hardware related actions is about 40 - 50% of the total engineering time. The tasks in this area have been split into two main categories, namely Wirings and Mechanical Components . The Wirings activity includes installation of all possible wirings that has been installed into the system, such as: electric cables, ethernet cables, pneumatic cables, etc. Due to the modular construction of SmartFactoryOWL, there is a vast number of short cables, thus there is a need for a lot of crimping of plugins. This is a potential place for some failures, therefore a good planning in advance using computer aided engineering tools, such as ePlan is a great help. The Mechanical Components part includes the physical integration of the conveyor belts and the production modules (robot cell, laser cell, augmented reality, etc.). A lot of different mechanical tools such as screwdrivers, stripping knifes, wire cutters, drilling machine, etc. were used here. So, a good workshop with a high variety of tools is a must have. In case of external manufacturing of some particular mechanical components or parts it has to be considered that the delivery may have some delays. Therefore, technologies such as additive manufacturing could be a great help to improve this activity.

V. Conclusion and future work

Reconfigurable Manufacturing Systems (RMS) are considered to be the future system paradigm in the industrial production. They shall reduce the engineering effort needed for setting up or modifying industrial production system. Nevertheless, they are not established in the industry by now. One reason for this is that their main advantage – the reduced engineering effort resulting in lower costs – cannot be put into numbers, yet.

In order to determine these figures the engineering effort of today's automation systems must be known at first. Such data can be used as benchmark when introducing optimizations to the engineering process. Therefore – as a case study – the commissioning process of a subsystem of the SmartFactoryOWL has been recorded in detail. This process has not comprised all levels of the automation hierarchy, but the most relevant ones since the field and the control level are present in all automation systems.

As a result of the case study, several engineering categories and their associated effort in terms of time have been analyzed. For example, the aspects network configuration and process data assignment comprise 25% of the total engineering effort. So, approaches for the automatic communication engineering [11] cannot reduce the engineering time more than this limit. Furthermore, in this study complications during the setup process have been noted and proposals for simplification have been given.

In the future work, modifications of the SmartFactoryOWL will be accompanied in the same way. Since the factory is constructed – in the sense of RMS – in a highly modular manner, the results of the future studies will show if and how reconfiguration processes can benefit from the RMS principle. Therefore the results of the studies will be compared with the study presented in this paper to achieve a comparison.

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