Data-driven Component Configuration in Production Systems

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***Abstract*—In many factories, trying to model and develop a complex production system is considered a hard task, requiring efforts and time to the process engineers and system engineers. The production system is treated as a closed data driven system where the system development is motivated by the production time and the quality of products. The corresponding technical solutions for the evaluated result (e.g., for production time) are considered as the driving data of the production system, which can be developed to improve the productivity of the production system. On the other side, the production system is a cyber-physical system, which presents a unified view of computing systems that interact strongly with their physical environment. In order to raise the productivity, the production time and the quality of products must be evaluated regularly. The components in production systems must follow these results of evaluation and be configured with a new architecture to achieve the new requirements. Thus, the challenge is how to follow the driving data to get the new component configuration in production system, particularly cyber-physical system. This paper will give an approach for modeling of the production system and generating of a candidate of component configuration in consideration of the driving data.**

Keywords*–*Architecture Evolution; Semantical Matching; Configuration of Components; Cyber-physical System.

I. INTRODUCTION

Cyber-Physical Systems (CPS) play important roles in many areas, e.g., smart factory, digital manufacturing, smart logistics, and energy efficiency. The modern mechanical engineering products are increasingly being supplemented by programmable controllers. Production system is a classical Cyber-Physical System. It is in constant evolution and should permanently be operated in order to raise the productivity or meet the continuously and fast changing requirements [1]. However, in general a production system is not defined perfectly at the beginning. And sometimes, it has to monitor itself for its productivity. Besides, driven by availability of new technology the production systems are repeatedly enhanced and extended in their prolonged life time.

An existing production system (see Figure 1) can be modeled with a component oriented modeling language. By using of an equivalent representation, the component oriented model for the existing production system is transformed to a graph structure, which keeps the system structure and properties from the original component oriented model [2]. This graph structure evolves into more different graphs by using of graph-based algorithms. Each new graph represents a new components configuration. By using combination rules, which are defined by system engineers, a part of the new component configurations, which meet the requirements of the driving data, can be found out. One of these configurations will be simulated and as a new production system implemented. This new one is named target 1 and will be continually evaluated into the second iteration.

In this paper, an approach is introduced to model and generate a candidate of component configurations for a plan of new production system according to the driving data. Firstly, the related work about the solutions of this problem will be introduced in Section II. Then, an example is presented in Section III reflecting the data driven evolution of production system. The necessary basics and fundamentals of this approach will be introduced closely related to the example system in Section IV. The approach is described in two parts in Sectionn V : the system architecture and algorithms. Finally, Section VI concludes and gives an outlook on further work.

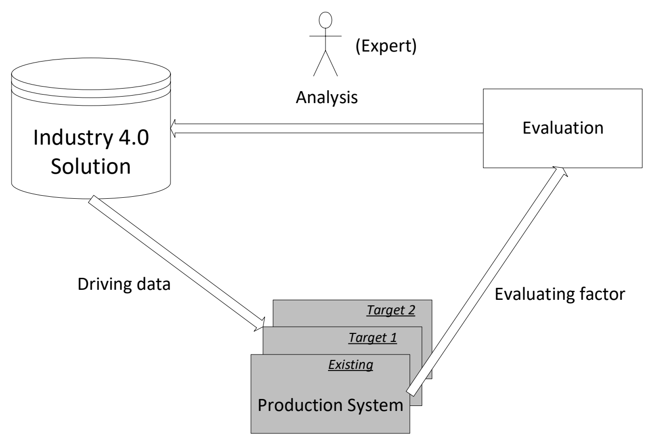

Figure 1. Data driven development of a production system

II. RELATED WORK

The “Industry 4.0” (I4.0) – also called “smart manufacturing” or “industrial internet of things” – in production is synonymous with highly flexible production, which enables companies to offer highly individualized products by linking the internet to conventional processes and services, and to actively involve their customers very early in the development process [3]. Currently, there are very less opportunities for the small and medium-size enterprises (SMEs) to gather the information which they need to adopt I4.0 solutions. In [4], an information portal is presented providing access to the results of a study commissioned by Stechert and Franke [5]. It reveals basic approaches to digitization and helps to identify business areas, such as product development that can be influenced by specific I4.0 functional areas. But the link to concrete I4.0 technologies does not take place here.

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As part of the project “Intro 4.0” [6], the implementation strategies of I4.0 solutions are developed based on four applications for participating industrial partners. Here, the specific I4.0 solutions are developed and introduced to industrial partners. The findings on the development and implementation of I4.0 solutions will then be used to derive recommendations for action on risk and potential estimation when implementing the I4.0 solutions [6]. However, the development of a simulation environment or the evaluation methodology for the comparison of alternative solutions is not planned.

The modeling of processes and information flows offers the sufficient resource for networking of the production planning systems, the control systems of machines, building systems and logistics systems [7]. The projects ENOPA [8] and EnHiPro [9] mainly committed to modeling between production planning systems and control systems of machines and logistics systems. The project PROFILE mainly devoted to description models for companies and the innovation and knowledge management in production networks. That is also the main work in the projects SynProd [10] and GINA [11].

The Functional Mock-up Interface (FMI) defines a standardized interface and is developed by Daimler within the framework of the MODELISAR project for the coupling of various simulation modules [12]. This approach is used to integrate simulation modules into other simulation modules with a common interface. A master simulation is defined, in that the appropriate different modules can be coupled. The data exchange between the modules must also be modeled in the master.

All these previous solutions have in common that although they allow a technical integration of different models they do not give a set of suitable concepts for structuring and integration of the concrete I4.0 solutions in the existing production system. So, the I4.0 solutions must be integrated in the existing production system before the evaluation of the I4.0 solutions.

III. Example System

Figure 2 shows a battery manufacturing system as an example. It consists of a 3D-print station, a quality assurance station, a battery module assembly, an electronics assembly, a final assembly, a storage for assembly (such as caps, batteries and electronics), a logistic system, a central controller and two robot grippers as transportations. The manufactured batteries will be transported into a warehouse and stored there.

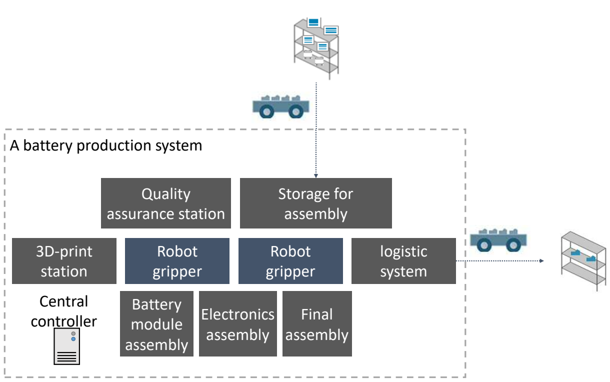

Figure 2. Battery production system as example

This battery manufacturing system is a classical CPS. The manufacturing parameters and the description of production processes are provided from another system as the input data to the central controller. The central controller networks the work stations, assemblies and other subsystems together to execute the production plan. The material and resources are transported into the storage for assembly and after the production the batteries are transported out from this system.

In this case, the production time is an important evaluating to reflect the productivity. Therefore, an evaluation system is monitoring this evaluating factor and in this way makes the evaluation of productivity. The evaluation results are analyzed to obtain one industry 4.0 solution. In this case, ”Track and Tracing with RFID” technology is selected using to optimize the production time (see Figure 3): One or more new RFID-reader sensors will be integrated into the existing production system and the RFID-chips must be integrated into the transport trays.

But there are many possible implementations to integrate the RFID-reader sensors into the existing production system. Thus, before the implementation or simulation of one integration concept, a decision support is necessary.

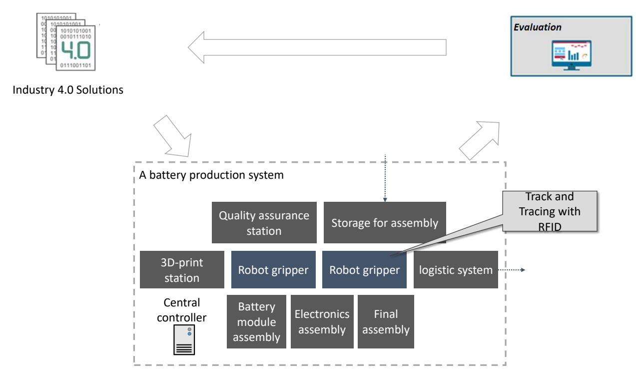

Figure 3. The technical solutions of the evaluated result for this battery production system as example

IV. Basics and Fundamentals

A. Component-based modeling

Internal Block Diagram (IBD) is a UML 2 based standard component oriented modeling language and used in Systems Modeling Language (SysML) for systems engineering [13]. The IBD consists of system components, interfaces in the form of ports and connections. Their symbols and interpretations are described in Figure 4.

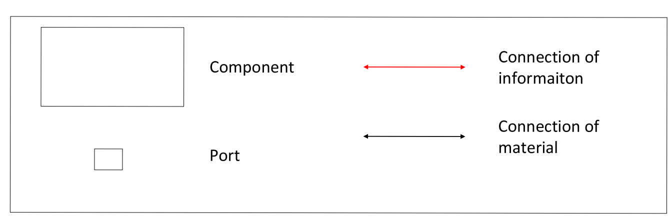

Figure 4. The interpretations of the symbols in IBD

The above mentioned existing state of the battery manufacturing system is modeled model with IBD in Figure 5.

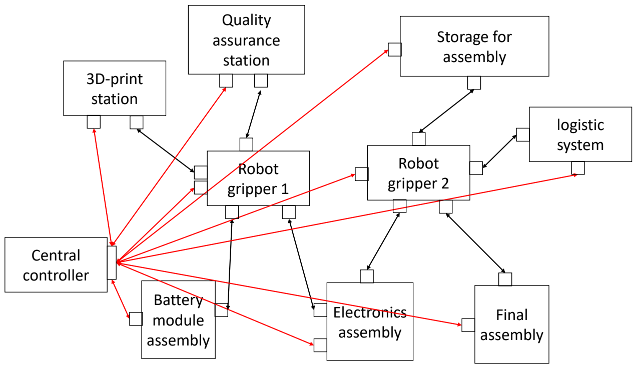

Figure 5. The existing production system modeled with IBD

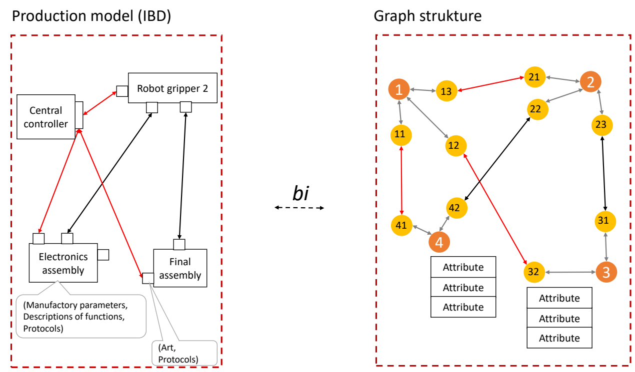

Figure 6. The graph representation of the existing production system

B. Graph structure

In order to describe the system evolution from exsiting state to a target state, a directed graph structure is introduced in definition (1). The elements in the set V represent the nodes of the graph structure G. Any element in the set E represents a directed edge (arrow) in G. The edges can be also described with $E := V \times V$. The functions src and tgt are two connection relationship functions for every edge, which connects to its source node with function src, as well as its target node with tgt. Every node and edge has attributes to store the semantic information (description information). Every attribute has a key-value structure, where P represents the power set of key-value pairs. The keys are identification keys and help identify the various kinds of description information, which are stored in values.

$$\begin{aligned} \mathcal{G} &:= (V, E, src, tgt) \\ src &:= src|_{E \to V} \\ tgt &:= tgt|_{E \to V} \end{aligned} \tag{1}$$

$$\begin{aligned} attributes &:= V \cup E \to P(Key \times Value) \\ Key &:= a\ set\ of\ values \\ Value &:= a\ set\ of\ values \end{aligned} \tag{2}$$

C. Transformation between models and graph structure

A transform function bi represents the transformation between IBD models and graphs. This transformation is defined as an equivalent and reversible transformation.

$$bi(m_{IBD}) \leftrightarrow g_{IBD} \tag{3}$$

Following the example of battery manufactoring system, a representative part in the full system is selected to clearly and detailedly introduce the transformation for every elements. In that, the system components and ports are transformed into nodes, and all connections to edges. (see Figure 6)

The system components like central controller, robot gripper 2, electronics assembly and final assembly are transformed to nodes 1, 2, 3, and 4 (see Figure 7). The belonging descriptions, like the manufactory parameters, descriptions of functions and protocol, are transformed into the attributes of the corresponding node. All of the interfaces are transformed to nodes in the graph. In this example, the digital (second) interface of the final assembly system component is transformed to node 32 in the graph, and its descriptions, like art and protocols, are saved in the attributes of node 32. All of the material flows and information flows are transformed to edges in the graph, at the same time the connection relationships are kept through this transformation.

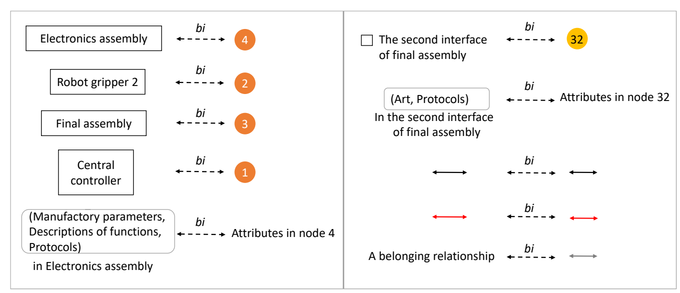

Figure 7. The interpretations of transformation between the IBD elements and graph elements for the existing production system

V. Approach

A. System architecture

Our approach is based on a subsystem named candidates generator. Figure 8 shows a new system architecture of data driven development of production system with this approach.

The inputs of candidates generator consist of one production model, which describes the existing state of the production system with IBD (1) and one Industry 4.0 solution (2). The outputs of candidates generator is a set of models for a target production system (3), which is integrated with the given industry 4.0 solution. At the same time, this set of models must be implementable. In the case of battery manufacturing system, the candidates for a new production system should consider with the integration of RFID-reader sensors into the existing production system. In the circumstances, any model in the candidates who cannot satisfy this condition will be removed from the candidates.

The filtered models will be continually evaluated with evaluating factors (4), such as production time and so on. After the evaluation, one production model is selected as a target model (5) and analyzed by experts (6) again. These processes

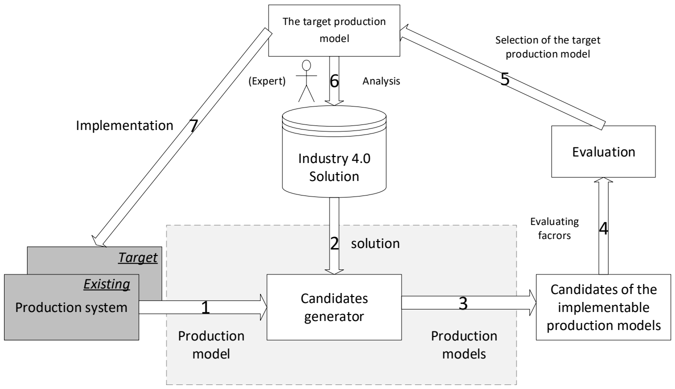

Figure 8. A new system architecture of data driven development of production system with our approach

make the generating an iterative loop possible, in order to apply more than one Industry 4.0 solution on a production system. After the integrations for all of Industry 4.0 solutions, the finally selected target production model will be implemented (7) to a new (target) production system. The new production system can be continually developed in the second iterative process into candidate generator.

B. Algorithms

The production model for the existing state is transformed into graph structure without information loss and structural changes by using the transformation function bi (see definition 3). On the graph structure, the algorithms in graph theory, e.g. depth-first search, breadth-first search, path/walk morphism and shortest path problem, can easily be used to generate new graphs. The transformation function bi makes the reversible from graph structure to production model possible and without information loss and structural changes.

VI. Conclusion and Further Work

We proposed an approach which supports the further development of complex cyber-physical systems. In the application example, the algorithm used in our approach had to give recommendations for integrating RFID-reader sensors in the existing production system. The existing models were first abstracted to a common graph-based description. The candidates generator was then used to determine candidates with a possible integration of the new components. Based on this set of candidates, an optimal integration of the new components can be identified.

The underlying concept is currently being continuously further developed and applied in the research project "Synus" to optimally integrate Industry 4.0 solutions into existing systems. This is intended to provide SMEs in particular with a decision-making aid for the introduction of new technologies.

Acknowledgment

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