Systematization Approach for the Adaptation of Manufacturing Machines

Xuan Luu Hoang, Alexander Fay
Institute of Automation Technology,
Helmut-Schmidt-University,
Hamburg, Germany.
{xl.hoang, alexander.fay}@hsu-hh.de

Philipp Marks, Michael Weyrich
Institute of Industrial Automation and Software Engineering
University of Stuttgart,
Stuttgart, Germany.
{philipp.marks, michael.weyrich}@ias.uni-stuttgart.de

Abstract— Existing production systems need to become more flexible and reconfigurable in order for manufacturing companies to stay competitive in nowadays highly dynamic markets. To achieve this goal, existing machines have to undergo various kinds of adaptation processes. As currently there is no standardized procedure, adaptations are mostly individually performed which results in a time-consuming and error-prone process. A systematization of the adaptation process could guide engineers through this complex task and may reduce errors and execution time. Thus, this paper is aimed at proposing a systematization approach for the adaptation of manufacturing machines. The application of the approach is illustrated by an adaptation scenario of a testing machine.

Keywords—adaptation, systematization, manufacturing machines, modernization

I. INTRODUCTION

Nowadays, manufacturing companies have to encounter highly dynamical markets, as product lifecycles become shorter and demand behaviors of customers change more quickly [1]. In order to ensure competitiveness within such turbulent environment, manufacturing systems and machines are obliged to be flexible and reconfigurable [2].

Newly designed manufacturing machines usually provide a certain degree of flexibility and/or reconfigurability to cope with quickly changing production requirements. However, in companies also a large number of existing machines are utilized for the manufacturing of goods. A high percentage of those machines was not designed for changing production requirements and thus, are quite inflexible. Due to this inflexibility, existing manufacturing machines can rapidly become obsolete if, e.g., new product variants are launched, new skills or process technologies are needed or production quantities have to be adjusted [3, 4]. In order to keep those existing manufacturing machines fully operative and to increase their lifetime, adaptations have to be performed, comprising changes in the physical structure of a machine and/or its automation software.

Although the term adaptation is used in a similar fashion for describing the evolution of a system with regard to changing environmental conditions in different domains [5, 6], the adaptation process of manufacturing machines itself is not standardized and often individually performed for each case.

Only few authors have proposed approaches for the support of adaptation processes of industrial automation systems [17, 19]. However, these approaches do not address the complete adaptation process nor the adaptation of manufacturing machines. While conducting adaptation actions, various interrelations within a machine have to be analyzed, in order to obtain fulfillment of requirements and to avoid unintentional changes of the system behavior [7]. As a result, each adaptation process starts almost "from scratch" and is a time-consuming, error-prone process and highly depends on the knowledge of the operating staff. A systematization approach for the adaptation could guide engineers through this complex process and may allow a more accurate evaluation of adaption efforts and benefits in a preliminary stage.

Accordingly, the aim of this paper is to present a systematization approach for the adaptation of manufacturing machines, which provides a systematic way of analyzing manufacturing incapabilities and adaption actions. The approach is applicable for various types of machines.

The rest of the paper is organized as follows: In Section II a review of related work is presented. Subsequently, the proposed systematization approach is described in Section III and illustrated by an adaptation scenario in Section IV. Finally, in Section V the paper closes with conclusions and an outlook on future work.

II. STATE OF THE ART

Reasons for the adaptation of manufacturing systems and machines are manifold. Westkämper identified eight influence factors for the dynamic adaptation of industrial production [6]. Driven by market and customer requirements, new product technologies and process technologies, Westkämper draws an image of the "Next Generation Factory" which is "adaptive, transformable, high-performing and intelligent" at the same time [6]. To achieve this goal, various approaches for the design of new manufacturing systems have been investigated and discussed in literature.

Flexible Manufacturing Systems (FMS) include a certain amount of foreseen flexibility [8, 9] and later were evolved to Agile Manufacturing Systems [10]. To overcome the

This research is supported by Deutsche Forschungsgemeinschaft DFG within the research project FlexA (FA 853/9-1 and WE 5312/5-1)

978-1-5090-1314-2/16/$31.00 ©2016 IEEE

limitations of FMS, Reconfigurable Manufacturing Systems were presented by Koren et al. [11]. Decentralized approaches like Holonic Manufacturing Systems [12], the paradigm of multi-agent systems [13] and lately especially the use of Cyber Physical Systems (CPS) in manufacturing [14] have been discussed for the flexibilization of new manufacturing systems.

Although these approaches have been subject of research for more than two decades, their use in industry is still limited. One reason is that the number of greenfield projects in high-wage countries is decreasing, while the number of plant modernization projects is increasing [15]. Nonetheless, most research projects focus on the early stages in the plant lifecycle while adaptation of existing machinery is hardly investigated [16].

In adaptation projects, the current modus operandi includes manual investigation of the system to be modernized and an experience based analysis of possible system changes. Only few approaches aim at supporting the adaptation process. They will be presented in the following.

Beyer et al. present an assistance system for the knowledge-based planning and adaptation of industrial automation systems [17] but without considering the characteristics of manufacturing machines. The concept was generalized from the intralogistics domain [18] and assumes for the adaptation process that the system was initially planned using the same assistance system.

Strube introduces tool-support in the process of modernization planning [19] based on a systematic modelling of the automation system. His work is focused on determining the impact of adaptations and not on the definition of a systematic adaptation process itself.

Literature review revealed that currently there is no methodology and systematization for the adaptation of single manufacturing machines which supports systematic and tool-aided modernization processes. Hence, the systematization presented in this paper seems to be of central importance when it comes to empowering existing manufacturing machines to compete in nowadays dynamic environments.

In literature, the terms modernization, evolution and retrofit are often used in the same or likewise meaning as adaptation. In the following, the term adaptation will be used for modifications of manufacturing machines aiming to enhance the flexibility of the machine. Adaptation comprises changes in the hardware and/or software of the manufacturing machine in order to integrate new functionalities, to enhance existing functionalities, to establish new material flow connections and to alter its output quantity.

III. SYSTEMATIZATION APPROACH FOR THE ADAPTATION OF MANUFACTURING MACHINES

The proposed systematization approach for the adaptation of manufacturing machines is based on two aspects: A) manufacturing capability characteristics of machines and B) adaptation categories. In the first two steps of the systematization, manufacturing capability characteristics that are linked to current manufacturing incapabilities are identified and analyzed. Depending on this analysis, adaptation actions of three categories are performed in the third step. An outline of the systematization is depicted in Figure 1.

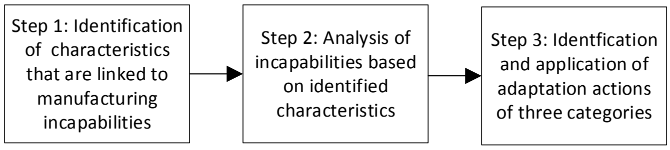

Figure 1: Outline of proposed systematization

In the following subsection, different types of manufacturing capability characteristics are introduced and systematization Step 1 and 2 are described. The second subsection presents adaptation categories and their relation to the characteristics (Step 3).

A. *Manufacturing capability characteristics of machines*

The manufacturing capability of a machine depends on four different types of characteristics, which are namely:

- C1: Set of different manufacturing operations
- C2: Parameter range of manufacturing operations
- C3: Set of feasible sequences of manufacturing operations
- C4: Range of output quantity

In order to manufacture products, different operations, e.g. milling and drilling, are needed and hence, the set of operations (C1) has a crucial impact on the manufacturing capability of a machine. The parameter range of operations (C2) is another a deciding factor for producing goods, as they determine e. g., which geometrical dimensions of a workpiece can be manufactured. Furthermore, in order to execute production processes, usually a sequence of multiple operations has to be performed in a scheduled order. A product cannot be manufactured if the needed operation order is not executable by a machine. Thus, the set of feasible operation sequences (C3) has an impact on the manufacturing capability of machines as well. The producible range of output quantity (C4) of a machine does not influence the technical manufacturing process of products directly but is a relevant characteristic with respect to the fulfillment of production orders.

Hence, if a machine is not capable of manufacturing a certain product, the causes of its incapability are directly linked to one or multiple of the presented characteristics. Thus, the first step in an adaptation process is the identification of the characteristic(s) which is/are related to the non-fulfillment of production requirements. Based on the identified characteristics, different analyses have to be performed (Step 2) which are briefly described in the following:

- *Insufficient set of different manufacturing operations:*

In case of an insufficient set of manufacturing operations, missing operations have to be identified which are needed for the manufacturing of a product.

- *Insufficient parameter range of manufacturing operations:*

If C2 is the restricting characteristic, the components (mechanical, electrical, software) which are linked to the restricting parameter ranges have to be identified.

- *Insufficient set of feasible manufacturing operations sequences:*

If the scheduled operation sequence is not executable, the material flow system within a machine has to be analyzed. As a result, missing connections between workstations are identified which restrict the execution of the scheduled operation sequence.

- *Insufficient range of output quantity:*

If the required output quantity of the production order cannot be fulfilled, the critical production path of the machine has to be analyzed. Here, information about bottlenecks and options for adjusting the output should result from the analysis.

B. Adaptation categories

In order to overcome manufacturing incapabilities, which root in the presented characteristics, various adaptation actions can be performed. In this approach, these actions have been classified into three categories. In each category different information and analyses are needed for deriving concrete adaption actions. Within the analyses the feasibility and effort of potential adaption actions have to be checked and evaluated. In the following the three categories are presented and shortly discussed:

- *Category A: Integration of manufacturing operations*

Adaptation actions in this category strive for the integration of additional manufacturing operations to the machine. To achieve this, physical components can be added or replaced with related changes in the control software. Furthermore, the physical position of the new components has to be determined. In this context, information about installation space and interfaces of components is required.

- *Category B: Adaptation of operation parameter ranges*

In this category, modifications of the control software and/or in the physical structure of a machine are applied to adjust insufficient operation parameter ranges. Within these actions, components that restrict the relevant parameter are identified. Furthermore, their physical and functional dependencies to other components have to be analyzed [20], in order to avoid unintentional changes of machine behavior.

- *Category C: Adaptation of material flow*

Actions in category C deal with changes of the material flow to create new connections between workstations or to adjust existing connections in order to enable the transport of new workpieces. Such actions can include software-related modifications and/or changes of the physical structure. Here, the existing material flow system has to be analyzed in order to derive possible modifications.

Based on the characteristics that are linked to the manufacturing incapabilities and the results of their analyses (see subsection III.A), actions of different adaptation categories are necessary to overcome these limitations. In case of an insufficient set of different manufacturing operations (C1), actions of category A can be applied to add missing operations. If parameter ranges of manufacturing operations (C2) are the limiting factors, adaptation actions of category B should be considered for adjusting the relevant parameters. Regarding an insufficient set of feasible manufacturing operations sequences (C3) actions from category C can be conducted to create needed material flow links for the required operation sequence. In case of the last characteristic (C4: Insufficient range of output quantity), actions of all three categories could be applied to overcome the incapability. For example, in order to increase the output quantity, processing times of certain operations could be reduced (category B) or a second parallel production path could be constructed (category A and C). The relations between characteristics and adaptation categories are summarized in Table 1.

Table 1: Relations between characteristics and adaptation categories

	Category A	**Category B**	**Category C**
C1	X		
C2		X	
C3			X
C4	X	X	X

After applying an adaption action of a certain category, it has to be checked if all production requirements are fulfilled or if further incapabilities exist. For instance, after integrating operations by constructing a new workstation (category A), the material flow may have to be adapted (category C) to fully integrate the workstation.

IV. EXEMPLARY APPLICATION OF PROPOSED SYSTEMATIZATION

In this section, the presented systematization is applied to an adaptation scenario of a testing machine. The machine is used for a fully automated, mechanical and electrical testing of dishwasher closures. The machine is comprised of six workstations and a rotary indexing table (see Figure 2).

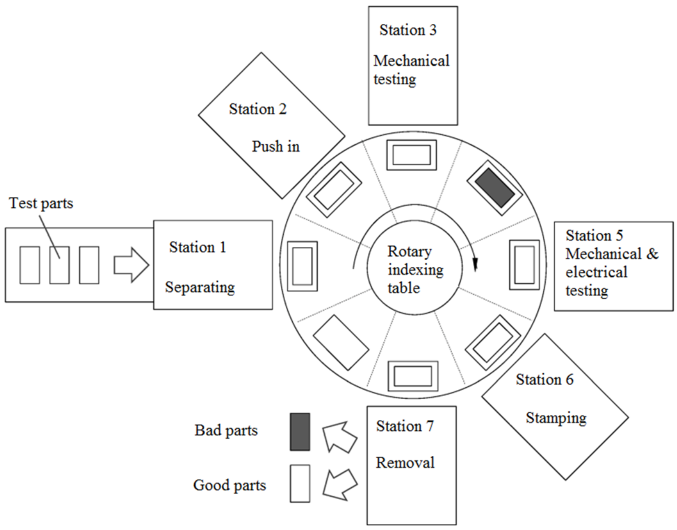

Figure 2: Overview of the testing machine

The first station separates the closures and subsequently places them on the rotary table. At the next station the test parts are pushed into the workpiece carrier. Mechanical and electrical tests are executed at stations 3 and 5. At station 6 a sequential number is stamped onto the test part. The last station removes the test part from the table and sorts them according to good and defective parts.

In the scenario, an RFID tag shall be added to each dishwasher closure which carries additional information (ID, testing date, etc.) about the product. For this purpose, a writing operation for RFID tags has to be added. Hence, characteristic C1 is linked to the manufacturing incapability. The missing operation could be implemented by constructing a new workstation. Therefore, adaptation actions of category A need to be applied. Before integrating a new workstation to the system, information about installation space and interfaces are needed. In this case, installation space is available between Station 3 and 5 (see Figure 2). Also communication and power interfaces are available for new sensors and actuators. Only software-related changes in the material flow system are required, as the new workstation would be already physically connected to the rotary indexing table. However, if the new workstation is located as described, the required testing sequence will not be fulfilled: a test part has to be fully tested before information is written onto the tag. Therefore, characteristic C3 has to be analyzed, and adaptation actions of category C have to be applied. Possible actions in this context are, e.g., changes in the control software of the rotary table or switching the location of Station 5 and the new workstation.

V. CONCLUSION AND OUTLOOK

The adaptation of manufacturing machines is a non-standardized, individually performed process that has not been systematized before. This paper presents an approach which comprises four types of characteristics that influence the production capability of a product on a manufacturing machine. To overcome the identified incapabilities, adaptation actions need to be performed. These adaptations are classified into three adaptation categories. Furthermore, relations between characteristics and adaptation categories have been described.

The goal of the ongoing research is to specify the analysis further and to transform the proposed classification into an assistance system for the adaptation of manufacturing machines. The assistance system will be able to guide the engineer through the adaptation process and will help to handle the variety of possible machine changes by evaluating profits and expenditures of each variant. Thus, a more accurate evaluation of adaption efforts and benefits in a preliminary stage can be achieved by using tool support.

REFERENCES

[1] H. Wiendahl and C. Heger, “Justifying Changeability. A Methodical Approach to Achieving Cost Effectiveness,” Journal for Manufacturing Science and Production, vol. 6, no. 1-2, 2004.

[2] M. Weyrich, F. I. Wior, D. Bchennati, A. Fay,. “Systematisierung von Flexibilitätsanforderungen von Industrie 4.0“, Werkstatttechnik wt-online, 2014

[3] M. G. Mehrabi, A. G. Ulsoy, and Y. Koren, “Reconfigurable manufacturing systems: key to future manufacturing,” Journal of Intelligent Manufacturing, vol. 11, no. 4, pp. 403–419, 2000.

[4] S. Rogalski, Flexibility Measurement in Production Systems: Handling uncertainties in industrial production. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011.

[5] F. Akkawi, A. Bader, D. Fletcher, K. Akkawi, M. Ayyash, and K. Alzoubi, “Software Adaptation: A Conscious Design for Oblivious Programmers,” in 2007 IEEE Aerospace Conference, pp. 1–12.

[6] E. Westkämper, “Digital Manufacturing In The Global Era,” in Digital Enterprise Technology, P. F. Cunha and P. G. Maropoulos, Eds, Boston, MA: Springer US, 2007, pp. 3–14.

[7] J. Ladiges, A. Fay, C. Haubeck and W. Lamersdorf, "Operationalized definitions of non-functional requirements on automated production facilities to measure evolution effects with an automation system," IEEE 18th Conference on Emerging Technologies & Factory Automation (ETFA), Cagliari, pp. 1-6, 2013

[8] J. A. Buzacott and M. Mandelbaum, “Flexibility in manufacturing and services: achievements, insights and challenges,” Flex Serv Manuf J, vol. 20, no. 1-2, pp. 13–58, 2008.

[9] H. A. ElMaraghy, “Flexible and reconfigurable manufacturing systems paradigms,” Int J Flex Manuf Syst, vol. 17, no. 4, pp. 261–276, 2005.

[10] A. Gunasekaran, “Agile manufacturing: Enablers and an implementation framework,” International Journal of Production Research, vol. 36, no. 5, pp. 1223–1247, 1998.

[11] Y. Koren, U. Heisel, F. Jovane, T. Moriwaki, G. Pritschow, G. Ulsoy, and H. van Brussel, “Reconfigurable Manufacturing Systems,” CIRP Annals - Manufacturing Technology, vol. 48, no. 2, pp. 527–540, 1999.

[12] J. H. Christensen, “Holonic manufacturing systems: initial architecture and standards directions”, Proc 1st Euro Wkshp on Holonic Manufacturing Systems, 1994.

[13] R. W. Brennan and D. H. Norrie, “From FMS to HMS,” in Agent-Based Manufacturing, S. M. Deen, Ed, Berlin, Heidelberg: Springer Berlin Heidelberg, 2003, pp. 31–49.

[14] G. Reinhart, P. Engelhardt, F. Geiger, T. R. Philipp, W. Wahlster, D. Zühlke, J. Schlick, T. Becker, M. Löckelt, B. Pirvu, P. Stephan, S. Hodek; Scholz-Reiter, B.; Thoben, K.; Gorldt, C.; Hribernik, K. A.; Lappe, D.; Veigt, M.: Cyber-Physische Produktionssysteme, wt-online - Ausgabe 2-2013 SONDERHEFT INDUSTRIE 4.0, S. 084-089

[15] M. Strube, S. Runde, H. Figalist, and A. Fay, “Risk minimization in modernization projects of plant automation - A knowledge-based approach by means of semantic web technologies,” in Factory Automation (ETFA 2011), pp. 1–8.

[16] Amberg, M., Holm, T., Belkius, B., & Tetzner, T. Benefits of Mechatronic Modeling associated with Plant Lifecycle Phases–A Literature Pre-Study. In Proceedings of the 12th International Business Information Management Conference (IBIMA2009), S (pp. 676-679).

[17] T. Beyer, N. Jazdi, P. Göhner, and R. Yousefifar, “Knowledge-based planning and adaptation of industrial automation systems,” in 2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA), pp. 1–4.

[18] T. Beyer, R. Yousefifar, S. Abele, M. Bordasch, P. Gohner, and K.-H. Wehking, “Flexible agent-based planning and adaptation of material handling systems,” in 2015 IEEE International Conference on Automation Science and Engineering (CASE), pp. 1060–1065.

[19] M. Strube, Modellgestützte Modernisierungsplanung industrieller Automatisierungslösungen. Düsseldorf: VDI-Verl, 2014.

[20] F. Zimmer, B. Böhm, A. Fay: Engineering relations as a concept for modelling dependencies and as a tool to reduce the effort in the planning phase. In: Kongress Automation 2015, Baden-Baden, 11.-12. June 2015.