Operational Classification and Method for Reconfiguration & Recommissioning of Changeable Manufacturing Systems on System Level

Mortensen, Steffen Tram; Madsen, Ole

Published in:
Procedia Manufacturing

DOI (link to publication from Publisher):
10.1016/j.promfg.2018.12.015

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 28 (2019) 90–95

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

International Conference on Changeable, Agile, Reconfigurable and Virtual Production

Operational Classification and Method for Reconfiguration & Recommissioning of Changeable Manufacturing Systems on System Level

Steffen Tram Mortensen*, Ole Madsen

Aalborg University, Department of Materials and Production, Fibigerstraede 16, Aalborg East, 9220, Denmark

Abstract

During the last decade, consumers have become accustomed to having access to a high variety of products and the expectation of frequent new product releases. Mass customization and changeable manufacturing systems are recognized as enablers. In particular, changeable manufacturing systems can quickly adapt to new market trends due to their ability to alter the manufacturing system according to the market demands. However, the ability to change also introduces unstructured and time-consuming reconfigurations and commissioning phases. This paper proposes an operational method to support reconfiguration and recommissioning in changeable manufacturing systems on a system level. The method is based on classification of elementary reconfiguration abilities and reconfiguration complexity. The proposed approach provides actions related to reconfiguration of hardware and software as well as actions related to commissioning tasks. In addition, the method also supports actions related to virtual commissioning.

Keywords: Changeable Manufacturing System; Operational Classification; Reconfiguration; Commisioning; Virtual Commissioning

1. Introduction

In the recent decades, consumers have become accustomed to having a high variety of products to choose from together with the expectation of frequent new product releases. Manufacturers have struggled to cope with the low-volume/high-mix with traditional dedicated manufacturing paradigms and manufacturing systems.

*Corresponding author. Tel.: +45-22361256;
E-mail address: steffen@mp.aau.dk

10.1016/j.promfg.2018.12.015

Mass customization has proven itself as a powerful manufacturing strategy for enabling low-volume/high-mix production. One of the enablers of mass customization is adaptable manufacturing systems such as Changeable Manufacturing System (CMS) [1]. CMS utilize modules with different functionalities enabling manufacturers to follow the market's demand while the system can change by reconfiguring the modules, e.g., exchange of modules on a system level to obtain a new scope of functionality [2]. A recent survey among industrial manufacturing companies indicated that reconfigurability enablers are only implemented to a very limited extent, thus indicating a need for methodological support for designing and operating changeable manufacturing systems [3]. Additional, recurrently unstructured and time-consuming reconfiguration and recommissioning phases (recommissioning is the commissioning phase following each reconfiguration in the system.) contribute to the fact that CMSs are not fully integrated in the industry yet [4]. Therefore, the scope of this paper is to address how:

Combination, classification, and operationalization of reconfiguration abilities and complexity can assist reconfiguration and recommissioning in changeable manufacturing system.

The modules of a CMS are usually mechatronics modules, containing both mechanic and controllable actuators/motors. Figure 1a, illustrates a CMS consisting of conveyor modules with placeholders for process modules, each side of the conveyor module has its own low-level controller, illustrated with the software demarcation line, controlling the conveyor and any attached process modules. The illustration is based on the AAU Smart Production Lab, further described in [5]. This paper will investigate a reconfiguration as a change both in hardware and software. In addition, we will only address reconfiguration on a system level, as defined in [6]. The remainder of this paper is divided into three sections. Section 2 gives an introduction to related work addressing the unstructured and time-consuming reconfiguration and recommissioning phase. A classification and operational method for differentiating the reconfiguration and recommissioning tasks are presented in section 3. Lastly, we discuss the developed method and present our considerations for further work in section 4.

2. Related Work

2.1. Reconfiguration Abilities

Several researchers have been addressing reconfiguration abilities in the literature. ElMaraghy and Wiendahl define one reconfiguration ability (org. *changeability classes*), for system level as *Flexible Reconfigurability* [7]. *Flexible Reconfigurability* is the ability to change the entire system by adding/removing modules altering the logistical, manufacturing, and material functions. Moreover, three reconfiguration abilities on system level have been presented in [8]. The first category refers to *product flexibility,* which categorizes modules in the system according to their flexibility, e.g., a module that may processes two products has higher *product flexibility* than a module only able of processing one product. *Operation flexibility* is the ability to reroute and choose a different sequence of operation to

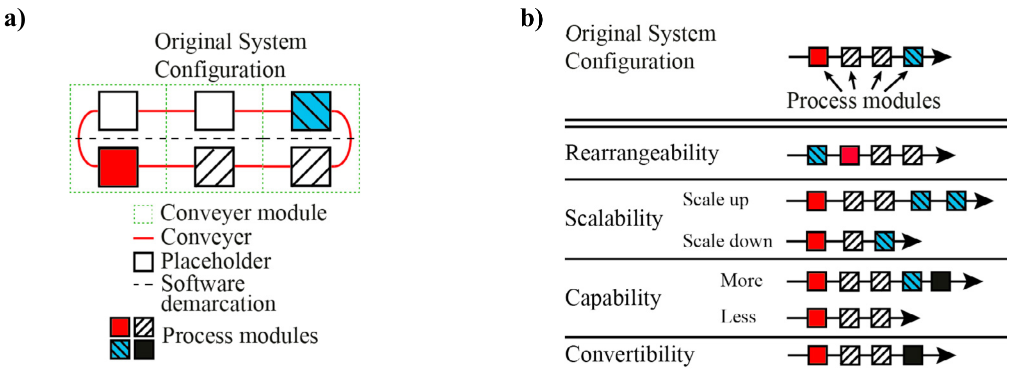

Figure 1: **a)** Illustrated a small configuration of a CMS with three conveyor modules, each with two conveyors and placeholders for process modules. A low-level controller controls each side of the conveyor module; **b)** Illustrated elementary reconfigurations abilities with an illustration of how the reconfiguration change the original system. Modified from [10].

produce various products. Lastly, *Capacity flexibility* is the ability to change the output volume. [9] present two reconfigurable abilities (org. *reconfiguration classes*): *Extensibility* and *Convertibility*. *Extensibility* is the ability to adjust the outcome, equivalent *capacity flexibility* in [8]. *Convertibility* is the ability to exchange modules with each other, thereby obtaining a new scope of functionality in the manufacturing system. In relation to the classification of reconfigurations abilities in [7], [8], and [9] we have previously identified four elementary reconfigurations abilities at the system level: *Rearrangeability*, *Scalability*, *Capability,* and *Convertibility*, illustrated in Figure 1b [10]. Note that for simplicity reasons, the conveyor in the illustration is straight and only the process modules are illustrated in comparison with Figure 1a. We can describe any hardware-and-software reconfiguration with the four elementary abilities. *Rearrangeability* is the elementary ability to change positions and thereby the sequence of modules in the system without changing the functionality of the CMS. Functionality is defined as the number of product variants the system can address. *Rearrangeability* can to some extent be related to *operation flexibility* in [8]. *Scalability* is the ability to handle changes of needed capacity for the system by duplicating or removing models without changing the functionality of the CMS, like *capacity flexibility* [8]or *extensibility* [9]. *Capability* is the ability to expand or decrease the functionality e.g., to handle larger or lower product variety within the system. Capability is related to *product flexibility* in [8]. *Convertibility* is the ability to exchange modules for changing the scope of functionality e.g., to change from being able to produce one product family to another, as also defined in [9].

2.2. Reconfiguration Complexity

It is recognized that reconfiguration of CMS may have different complexities. [11] presents a model describing the increasing complexity of changes in a manufacturing system in relation to the change of product. The classification of change of products and manufacturing systems is divided into three categories: *Exiting, Modified,* and *New*. *Exiting* is the ability to use the manufacturing system without any changes. *Modified* is the ability to modify the manufacturing system to produce the desired product, like in a CMS. Lastly, *New* refers to the need for a completely new manufacturing line. In [10] we presented a model for capturing the complexity of a reconfiguration inside a CMS. A reconfiguration task of a manufacturing system can be divided into three categories in relation to complexity and time consumption. *Known-to-Known* (K2K), *Known-to-Familiar* (K2F), and *Known-to-Unknown* (K2U). A *Known* configuration is a configuration known to a sufficient and document level that allows the configuration to be reproduced. A K2K reconfiguration is changing from a *Known* configuration to a previously used configuration. K2F reconfigurations are changing from a *Known* configuration to a configuration that exists inside the desired solution space of the system utilizing standard modules and standard interfaces. A K2U is a reconfiguration from a *Known* configuration to a configuration outside the solution space of the system but peripheral to the solution space, hence it requires a modification of standard modules and/or standard interfaces.

2.3. Reconfiguration and Commissioning Tasks

Reconfiguration from one configuration to another encompasses multiple steps. As defined previously a reconfiguration involves both hardware and software changes. The hardware changes involve physical work, e.g., unscrewing the modules, unplugging the power, air, and network supplies, physically movement of modules and reattaching modules in the new configuration. Software changes may involve, back-up of code, updates, programming changes and uploading of software to support the new configuration. In addition, software changes also might affect the high-level controller, e.g., change the product variant model (sequence of operation for the products) and/or the topology model (system layout model) in the Manufacturing Execution Systems (MES). After the reconfiguration is performed, it is time for the commissioning. The commissioning phase is both testing the physical setup and testing of low- and high-level software programs. 63% of the commissioning time is used to debug software [12]. It is, therefore, relevant to have particularly focus on lowering the commissioning time of the control software. One tool to assist this is virtual commissioning that may lower the commissioning time up to 75% [12]. Virtual commissioning, also called hardware-in-the-loop verification, test the real physical low-level controllers, in many cases programmable logical controllers (PLCs), against virtual devices. A virtual device is a virtual model of a physical entity, containing a physical device modeling (geometry and kinematic) and a logical device modeling (behavior). The virtual devices can be combined to realizing a virtual plant. A low- and high-level controller, such as MES and PLCs, can be verified by control of the virtual plant before implemented in the physical manufacturing system, thus, saving time in the commissioning phase. The physical commissioning follows the virtual commissioning and may contain, calibration of modules, level out the modules, check if I/Os are connected properly, standard test, e.g., emergency stop protocols, and test of that the product can physically be process in each module and may be transported in-between.

As stated above, several classifications of reconfigurability have been published. However, an operational method, with concrete action for each class to supporting the reconfiguration and commissioning phase in changeable manufacturing system was not found in the literature based on our literature review. In the following section, such method will be proposed on an operational level.

3. Method for Reconfiguration and Recommissioning of Changeable Manufacturing Systems

By combining elementary reconfiguration abilities and reconfiguration complexity, we can differentiate and classify reconfigurations on a system level in a CMS. Table 1 presents a comprehensive operational method for all combinations of elementary reconfigurable abilities and reconfiguration complexity. Each class of reconfiguration is divided into four subgroups; *Hardware* and *Software* reconfiguration, *Virtual Commissioning* and *Physical Commissioning*, described in the previous section. Action(s) related to each subgroup are listed in each class. The actions are identified as a result of combining knowledge from experience with changeable learning factories, deduction, and inspiration from the literature. In our view of CMS, Figure 1a, elementary abilities can be performed in two scenarios 1) Rearranging, scaling, adding/removing or exchanging process modules on top of the conveyor modules. 2) Rearranging, scaling, adding/removing or exchanging the conveyor modules without demounting the attached process modules. We have chosen actions related to scenario 1) since this is the most comprehensive scenario and contain actions for the second scenario. Note that performing virtual commissioning is not required for the use of Table 1 in order to support reconfiguration of CMS. It is evidence that moving from a K2K or K2F configuration towards K2U reduces the reuse of standardized modules in the manufacturing system and introduces a higher need for design and modification of standard modules. This also applies to the control software. The virtual recommissioning task also utilizes standardized virtual devices for constructing the virtual plant. We also assume that standard modules that are not currently present in the system are present in a catalog/warehouse or similar in order to obtain K2F *capability* and *convertibility*. Based on the support tool for reconfiguration and recommissioning of changeable manufacturing systems shown in Table 1, we propose the following method when performing reconfiguration and recommissioning of a CMS:

1) Recognize reconfiguration complexity
2) Identify needed elementary reconfiguration ability
3) Select class in Table 1
4) Perform the actions indicate for the class within hardware, software, optional: virtual commissioning, and physical commissioning.

Table 1: Support tool for reconfiguration and recommissioning of changeable manufacturing systems.

	K2K	K2F	K2U
Rearrangeability	**Hardware:** • Rearrange positions of standard modules in the system to previously known position **Software:** • Load previously used software into low-level controllers • Load previously used topology model to the high-level controller **Virtual Commissioning:** • Load previous used virtual plant model • Virtual plant commissioning	**Hardware:** • Rearrange positions of standard modules by use of predefined interfaces **Software:** • Interchange standard software modules to program low-level controllers • Rearrange the topology model in the high-level controller **Virtual Commissioning:** • Rearrange plant model based on used standard virtual devices • Virtual plant commissioning	**Hardware:** • Rearrange positions of standard modules by use modified interfaces **Software:** • Modified or modified & interchange standard software modules to program low-level controllers • Modify the topology model in the high-level controller **Virtual Commissioning:** • Modified interfaces of standard virtual devices • Rebuild plant model based on standard virtual devices with modified interfaces and with/without standard virtual devices • Virtual device commissioning • Virtual plant commissioning

	Physical Commissioning: • Physical calibration • High-level test	**Physical Commissioning:** • Physical calibration • High-level test	**Physical Commissioning:** • Physical calibration • I/O test • High-level test
Scalability	**Hardware:** • Duplicate/remove duplicated standard modules to obtain precious known capacity **Software:** • Load previously used software into low-level controllers • Load previously used topology model to the high-level controller **Virtual Commissioning:** • Load previous used virtual plant model • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • High-level test	**Hardware:** • Duplicate/remove duplicated standard modules to obtain a new capacity **Software:** • Clone software for duplicated modules to program low-level controllers • Expand/decrease the topology model in the high-level controller **Virtual Commissioning:** • Modify the plant model based on standard virtual devices • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • High-level test	**Hardware:** • Add modified standard modules with/without duplicate/remove duplicated standard modules to obtain a new capacity **Software:** • Clone and modify standard software modules to program low-level controllers • Modify the topology model in the high-level controller **Virtual Commissioning:** • Modify standard virtual devices • Rebuild plant model based on modified virtual devices and with/without standard virtual devices • Virtual device commissioning • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • I/O test • High-level test
Capability	**Hardware:** • Add/remove standard modules to obtain precious known functionality **Software:** • Load previously used software into low-level controllers • Load previously used topology model and variant model to the high-level controller **Virtual Commissioning:** • Load previous used virtual plant model. • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • High-level test	**Hardware:** • Add/remove standard modules to obtain new functionality **Software:** • Load new standard software modules to program low-level controllers • Adjust the topology model and expand/decrease the product variant models in the high-level controller **Virtual Commissioning:** • Modify the plant model based on standard virtual devices. • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • High-level test	**Hardware:** • Add modified standard modules with/without adding/removing standard modules to obtain a new functionality **Software:** • Combine and modify standard software modules to program low-level controllers • Modify the topology and product variant models in the high-level controller **Virtual Commissioning:** • Modify standard virtual devices • Rebuild plant model based on modified virtual devices and with/without standard virtual devices • Virtual device commissioning • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • I/O test • High-level test
Convertibility	**Hardware:** • Exchange standard modules to obtain previously known scope of functionality **Software:** • Load previously used software into low-level controllers • Load previously used topology model and variant model to the high-level controller **Virtual Commissioning:** • Load previous used virtual plant model • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • High-level test	**Hardware:** • Exchange standard modules to obtain new scope of functionality **Software:** • Exchange standard software modules to program low-level controllers • Adjust the topology and product variant models in the high-level controller **Virtual Commissioning:** • Modify the plant model based on standard virtual devices • Single virtual device commissioning • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • High-level test	**Hardware:** • Exchange modified standard modules to obtain a new scope of functionality **Software:** • Change and modify standard software modules to program low-level controllers • Modify the topology and product variant models in the high-level controller **Virtual Commissioning:** • Modify standard virtual devices • Rebuild plant model based on modified virtual devices and with/without standard virtual devices • Virtual device commissioning • Virtual plant commissioning **Physical Commissioning:** • Physical calibration • I/O test • High-level test

4. Discussion and Future work

The presented method enables more frequent reconfiguration of changeable manufacturing system, leading to a larger industrial implementation of changeable manufacturing systems. Previous related work has suggested that the introduction of reconfigurability can potentially lead to significant profits. However, in order to transform this potential into actual savings, a great effort is required to design the manufacturing systems in such wat that enable reconfigurability, and secondly to perform the actual reconfigurations. This paper contributes to filling the theory to practice gap in relation to the latter, by introducing high-level methodological steps. The identification and classification of elementary reconfiguration abilities lead to a more structured reconfiguration. The classification of complexity of the reconfiguration task supports a mindset and introduces the discussion of the reusability in a reconfiguration. The development of an operational method for reconfiguration and recommissioning on a system level of changeable manufacturing systems supports future working procedures. As future work, we consider to expand the proposed method further and test it in actual industrial environments.

References

[1] H.-P. Wiendahl, H.A. ElMaraghy, P. Nyhuis, M.F. Zäh, H.-H. Wiendahl, N. Duffie, M. Brieke, Changeable Manufacturing - Classification, Design and Operation, CIRP Ann. 56 (2007) 783–809. doi:https://doi.org/10.1016/j.cirp.2007.10.003.

[2] G.R. E Abele, P Nyhuis, Wandlungsfähige Produktionssysteme: Heute die Industrie von morgen gestalten, Verlag PZH Produktionstechnisches Zent. (2008).

[3] A.-L. Andersen, J.K. Larsen, T.D. Brunoe, K. Nielsen, C. Ketelsen, Critical enablers of changeable and reconfigurable manufacturing and their industrial implementation, J. Manuf. Technol. Manag. (2018). doi:10.1108/JMTM-04-2017-0073.

[4] A.-L. Andersen, T.D. Brunoe, K. Nielsen, M. Bejlegaard, Evaluating the investment feasibility and industrial implementation of changeable and reconfigurable manufacturing concepts, J. Manuf. Technol. Manag. 29 (2018) 449–477. doi:10.1108/JMTM-03-2017-0039.

[5] S.T. Mortensen, O. Madsen, A Virtual Commissioning Learning Platform, Procedia Manuf. 23 (2018) 93–98. doi:https://doi.org/10.1016/j.promfg.2018.03.167.

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

[7] H.A. ElMaraghy, H.-P. Wiendahl, Changeability – An Introduction, Chang. Reconfigurable Manuf. Syst. (n.d.) 3–24. doi:10.1007/978-1-84882-067-8_1.

[8] G. Chryssoluris, Manufacturing Systems: Theory and Pratice, 2005.

[9] A.-L.H. Nadège Benkamoun, Khalid Kouiss, An intelligent design environment for changeability management - application to manufacturing systems, in: ICED - Des. Organ. Manag., 2015: pp. 1–10.

[10] S.T. Mortensen, D. Chrysostomou, O. Madsen, A Novel Framework for Virtual Recommissioning in Reconfigurable Manufacturing Systems, in: 2017 22nd IEEE Int. Conf. Emerg. Technol. Fact. Autom., IEEE, 2017: pp. 1–4. doi:10.1109/ETFA.2017.8247744.

[11] H. Almgren, Pilot Production and Manufacturing Start-up in the Automotive Industry. Principles for Improved Performance, Chalmers University, 1999.

[12] G. Reinhart, G. Wünsch, Economic application of virtual commissioning to mechatronic production systems, Prod. Eng. 1 (2007) 371–379. doi:10.1007/s11740-007-0066-0.