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Brownfield Development of Platforms for Changeable Manufacturing

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Abstract

Typically, development of changeability and reconfigurability in manufacturing are greenfield approaches. New platforms, products and manufacturing systems are developed with new features, capability or technology. While companies can achieve the desired level and type of changeability with greenfield approaches, development of new platforms and systems is a costly affair if existing systems and platforms in the company is not considered. This study outlines an approach for systematic brownfield platform development. Seven stages are listed, describing how candidates for inclusion in a platform are identified and subsequently developed based on existing manufacturing systems and production landscape.

Keywords: brownfield development; changeable manufacturing; manufacturing systems; production platform

1. Introduction

Changeable manufacturing is becoming increasingly more interesting to companies looking to manage a still rising variety in an efficient manner [1,2]. Changeable manufacturing, and changeability in general, enables manufacturers to respond to the challenge of a volatile market with frequent changes in demand and new product introductions [1]. Manufacturers looking to adopt changeable manufacturing often have existing product portfolios, production systems and potentially platforms scattered throughout. These represent a large investment on the company's part. Considering and reusing these portfolios, systems and platforms rather than designing new ones from scratch, could significantly lower the barrier of entry during transition to changeable manufacturing.

Greenfield development, as opposed to brownfield development, is outside the constraints of prior work and existing systems. These approaches can still consider existing systems, but they are free to ignore most constraints. While most approaches for product and production platform development do consider prior work, they are typically focused on development of new platforms, modules and solutions [3,4]. In a similar vein, methods for reconfigurable and changeable manufacturing system design—while taking a manufacturer's requirements for changeability into account—usually focus on new modules and new systems, i.e. a greenfield approach [5,6]. This may be one of the reasons why relatively few concrete implementations and examples of changeable and reconfigurable manufacturing systems exist. It is, however, always recommended to perform an internal survey of existing systems to evaluate their potential for change [7].

Using a brownfield development method, existing solutions can be elevated to become platforms in their own right, rather than developing all new solutions and platforms. This can potentially be accomplished by identifying the most likely candidates for platforms among existing solutions. To standardise as many aspects of these candidates as possible, a number of conscious decisions are made and documented. Such decisions will determine which aspects of the platform may change, and which may not. Thus, when a new system is to be

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created, processes or functions frequently carried out in existing systems can be solved with modules and equipment in the platform, which have already been proven robust and efficient for their given task. This can free up development time for work on solutions for less frequent tasks, new technologies or overall efficiency improvements.

In this study, a systematic approach for brownfield production platform development is introduced. It consists of seven stages acting as operational guidelines. The approach focuses on the identification and subsequent development of candidates for production platforms based on existing production systems and infrastructure. To frame this research, the following research question has been formulated:

- What steps should a manufacturer take to develop platforms of standardised assets based on existing production systems and environments?

Firstly, the role of platforms in changeable manufacturing and design of changeable manufacturing systems (CMSs) will be clarified, followed by a description of the underlying method for the brownfield development approach. The approach and its seven stages are then presented, and finally the approach itself is discussed and the paper is concluded.

2. Platforms and Changeable Manufacturing

For products, platforms—often bringing modularity and standardisation—have long since proven useful in managing variety. These platforms are typically developed for the introduction of a new product, with the expectation that later product generations will be built upon the new platform and follow its principles of design [8]. Production systems generally have a longer lifecycle than the products they manufacture, meaning they are expected to manufacture multiple new product generations and platforms. The increasing interest in changeable manufacturing, and particularly reconfigurable manufacturing, is partly a result of this mismatch between lifecycles [1] . Design, development and implementation of changeable and reconfigurable manufacturing systems are however still a significant challenge.

Although methods for design and development of reconfigurable manufacturing systems have mentioned platforms briefly, the explicit role of platforms in design of changeable manufacturing remains unclear. In an attempt to rectify this, a simplified and slightly modified version of Andersen et al.'s [5] method is shown in Fig. 1. A dashed box has been added to illustrate in which design phases platforms can be utilised and provide a benefit for designers and developers, i.e. the final stages of basic design and throughout the advanced design phase.

Prior to the basic design phase, a development plan and a requirements specification are created. During basic design, these are used to define the degree of modularity, system elements, interfaces, modules and enablers of reconfigurability. Having a platform containing existing knowledge, procedures, decisions and modules with well-defined interfaces will be extremely beneficial in the later parts of basic design. Once the degree of modularity and requirements for reconfigurability or changeability have been defined, these can be used to search for existing solutions in the platform, and speed up the process of creating a concept.

During advanced design, the concept created in the basic design phase is turned into a detailed design. This is the physical design and construction of the changeable manufacturing system. Platforms play a key role in this phase. They contain options and guidelines available to designers of the system in terms of system modules, interfaces and physical equipment. Using these readily available solutions for advanced design can save the developers a lot of time, and potentially allow them to spend more time on critical tasks, e.g. introduction of new technology or optimisation of existing solutions, both resulting in an update to the platform.

Once the advanced design phase has been completed, the system can be implemented and operated. When a change in capacity or functionality is needed, the system can be reconfigured and operated with a new purpose.

3. Method

The approach presented in the following section was developed through an evolving case study in collaboration with an industrial partner. It was split into four consecutive projects with a varying group of participants. All four projects focused on development of platforms with the end-goal of facilitating changeable manufacturing. The four projects and their respective foci are shown on Fig. 2.

Each project built upon the previous, with increasing understanding of platforms. The first project sought to understand the nature of platforms, what to use them for and how to develop them. Through the second project,

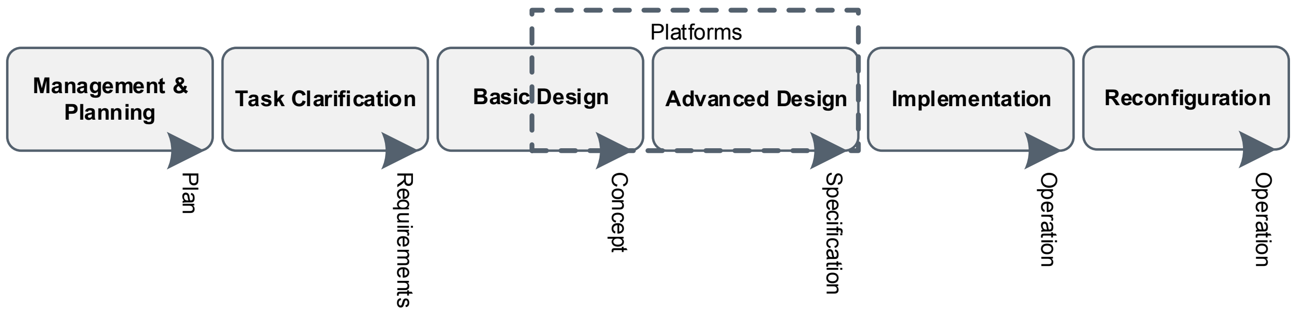

Fig. 1. Simplified version of Andersen et al.'s [6] generic reconfigurable manufacturing system design method. Added dashed box to highlight design phases where production platforms should be utilized and can provide a benefit. Vertical text is the output from each phase.

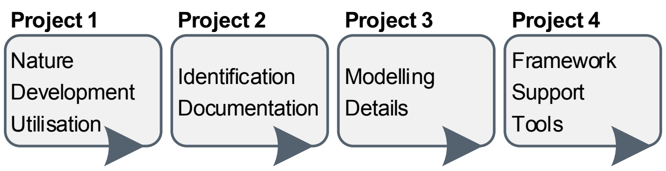

Fig. 2. Overview of the four platform projects in the evolving case study.

identification and documentation of potential platforms was explored, and in the third project a platform was modelled and documented in detail. The fourth project is still ongoing, and seeks to create a framework and supporting tools for platform development. Additional details on the four projects and the challenges encountered throughout are documented in [9].

4. Brownfield Platform Development

The approach for brownfield platform development listed below is a systematic approach. Its seven constituent stages are operational guidelines, not rigid prescriptions. While it is likely necessary to complete more than one iteration of certain stages, the stages should generally be carried out in order. Overall, the intention for the seven stages is to make the complicated platform development process more transparent and easier to understand. The approach is inspired by systematic engineering design [10] and goes through the same four basic design phases of planning and clarification (stages 1 and 2), conceptual design (stage 3), embodiment design (stages 4 and 5) and detail design (stage 6). Govern and maintain platforms (stage 7) falls outside these four phases, but is important for the continued function of developed platforms.

1. Assess changeability requirements
2. Identify platform candidates
3. Define essential functions
4. Establish principal structure
5. Define Physical Enablers
6. Document platform
7. Govern and maintain platforms

Stages 1 and 2 are carried out once per iteration of the seven stages. Once platform candidates have been identified in stage 2, stages 3-6 are carried out for each of the previously identified platform candidate. Stage 7 is a continuous stage that does not truly end, and which can trigger another iteration of the entire process, starting with a reassessment of changeability requirements. Between each individual stage of the approach, the current subject of development should be evaluated to determine whether continued development of the platform is justified—it is essentially a stage-gate approach. Platform candidates, for which no justification for continued development can be made, skip the remaining stages and are noted as part of platform governance and maintenance (stage 7). Thereby, development can resume if justified and need arises, and reasoning for stopping development is available for developers until then.

This paper focuses on stages 2-6, but will briefly cover stages 1 and 7, which are considered and part of an overarching platform framework. For stages 3-5, an industrial robot cell is used as an example of a platform candidate. In the following sections, each stage of the approach will be elaborated.

4.1. Assess Changeability Requirements

Assessment of changeability requirements for a specific company, factory or production segment sets the scope for all subsequent stages. This ensures that the end-goal of platform development is clear to all participants and stakeholders, as well as defining the areas of departments of the company to focus on.

Through the assessment, a company's needs related to changeability are screened. Change drivers and objects are determined, along with the recommended type and degree of changeability and an estimation of the potential benefits of implementing CMS. This also leads to the selection of production systems for which platforms will be developed.

A primary facilitator in this regard is the participatory systems design method by Andersen et al. [6]. The method considers existing products, production, technologies and facilities to recommend a path to changeability for a specific company. It accomplishes this through a questionnaire answered by stakeholders and experts in the company, followed mapping of answers to requirements, manufacturing paradigms and physical enablers.

4.2. Identify Platform Candidates

Production platform candidates are essential functions, processes, equipment or knowledge that should be investigated further for development into platforms. Further development of individual candidates should be done in projects dedicated to one or more platforms, or in projects leading up to the use of specific platforms. In this stage, a number of such potential future platforms are identified. The platform identification process is summarised in Fig. 3. Often, this identification of candidates is a task for system stakeholders and experts, who mainly rely on their intuition and (often tacit) extensive knowledge of specific systems. What system experts base their decisions on can vary greatly, but it is not unusual for commonality or similarity to form the basis for product families or platforms [11,12]. Commonality can be identified e.g. by finding similar components [13], geometries [14] or production processes [15]. Similarly, commonality can form the basis for identification of production platform candidates.

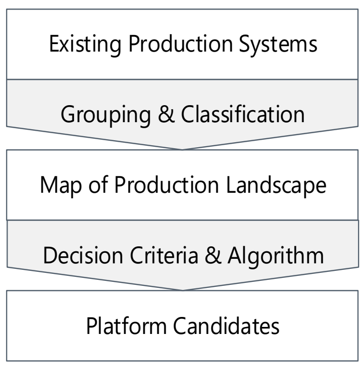

Fig. 3. Overview of the platform identification stage. White boxes represent input/output and grey boxes represent a process.

Regardless of the specific type of commonality used to identify candidates, data on the entities or systems of interest is a requirement, i.e. a map of the current production landscape. Entities or systems of interest should be classified or grouped to facilitate comparison and identification of commonality across systems and departments. Group technology and classification coding is a systematic way to classify entities in order to form groups or families. It is typically used to classify products or components, but few coding schemes exist for classification of manufacturing systems [16,17].

Once classified, decision algorithms can be applied to suggest platform candidates based on factors related to the company's specific changeability requirements and criteria. These criteria can be determined based e.g. on the company's roadmap in terms of lifecycle for current products and systems, planned changes, variety, service and maintenance. For instance, a critical process appearing in many systems with a high cost and varying performance is a prime candidate for standardisation and thus a platform candidate. A more detailed look into criteria and factors for platform identification is the subject of a forthcoming publication. Classification of the current production can also assist system experts in making decisions without strict algorithms, but algorithms can be useful for increasing objectivity and identifying candidates less obvious to system experts.

4.3. Define Essential Functions

Essential functions (or functional elements) are intangible design elements in the functional domain of a particular platform candidate (module, platform element etc.). They are functions that must be carried for a system to fulfil its purpose. A standardisation of these functions means a standardisation of a system's functional capability.

To define the functions of a platform candidate, its top-level function must be identified and broken down into partial sub-functions. It can be beneficial to include both functions and the means to carry out each function, e.g. with a function-means tree, as this guides the decomposition into sub-functions. Such a model can also be used to illustrate differences in how functions are carried out throughout the company.

Each platform candidate should also be represented with a function sequence describing what exactly the candidate does. A function sequence makes it simple to grasp the function of a platform candidate at a glance, and can be illustrated with a simple process flowchart. If a platform candidate can carry out multiple top-level functions, such as an industrial robot capable of carrying out either an assembly process or a material handling process, both of these top-level functions should be represented by their own function sequence.

The outcome of this stage is a list of functions a platform candidate must carry out, and the means with which it does so.

4.4. Establish Principal Structure

The principal structure describes the interactions between elements of a given platform candidate, and the candidate's interactions with the environment. It represents a simple view of a platform candidate's architecture. At this stage, interactions are not fully specified, but they are identified and given a corresponding type (e.g. spatial, energy, information or material [18]).

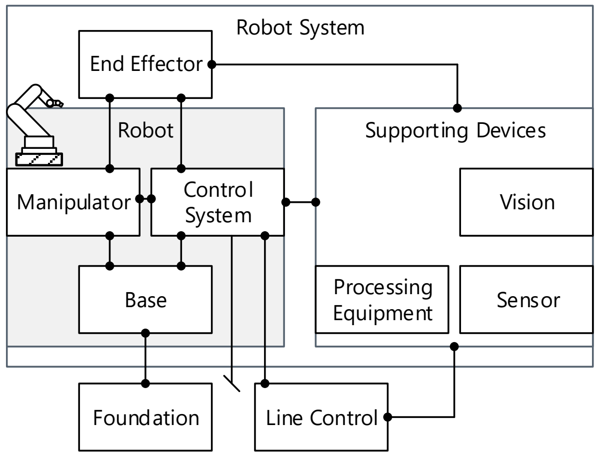

Fig. 4. Principal structure of a robot system consisting of a robot, an end effector and supporting devices. The grey box represents the robot itself.

The principal structure can be established by closely investigating existing physical instantiations of the selected platform candidate. A simplified example using a robot system with the robot itself in focus is shown on Fig. 4. As shown, the robot system consists of a robot, an end effector (e.g. gripper or tool) and a number of supporting devices. The robot itself consists of a manipulator facilitating movement, a control system controlling movement and a base supporting the robot and connecting it to the foundation. Both manipulator and control system are connected to the end effector. The control system is also connected to the supporting devices, line control (control system for the manufacturing system the robot system is part of) and a supply.

To keep the illustration simple, interaction specifications and additional interactions between the robot system and its environment have been removed.

4.5. Define Physical Enablers

Each of the elements shown on Fig. 4 have varying physical enablers appropriate for specific areas of application. In this case, enablers refer to physical instantiations of manufacturing equipment facilitating a particular operation or process. Transforming or developing a platform candidate into a platform does not necessarily mean making or choosing an enabler for all applications, but rather having a few well-defined enablers that span a range of applications. A robot will not be fit for all material handling applications, and a screwing machine will not be fit for all joining applications.

As the first part of defining physical enablers, a set of key requirements should be specified. These requirements are the basis on which different enablers are compared. They are the design driving requirements for the platform candidate, and thus the physical enablers. For the previously mentioned robot example, some of these may be e.g. maximum load, maximum reach, accuracy etc., depending on what is important to the developer.

The design driving requirements are then used to form areas of application under which existing enablers can be grouped, e.g. low payload robots for material handling processes, high accuracy and low payload robots for manufacturing processes etc. For each of these areas of application, all existing enablers are listed. Based on the performance of individual enablers (and number of identical enablers, should any such exist) a conscious decision must be made on whether the enabler should be used in future systems. Each selected enabler should then have their principal structure detailed into physical structure. The physical structure includes a specification of each element and interaction in the principal structure, e.g. type, version and connections of the robot control system and interface standard, screws and geometry for the interaction between the manipulator and end effector.

Any enabler deemed inappropriate in future systems will remain in use in its current system, but it will not be documented for reuse. Once the lifecycle of the enabler or its related product has reached its end, a new version will not be bought.

4.6. Document Platform

Platform documentation is often overlooked as a phase in the development of platforms, and the platforms are simply assumed to exist in some form. It is, however, a crucial stage in the development of platforms and a requirement for their utilisation in a company.

Platform documentation can take many shapes. It should gather up all the models, decisions and reasoning etc. from the previous stages. A key aspect is that the documentation must be accessible to all relevant stakeholders, regardless of their level of understanding or their specific concerns regarding the platform. This can, for instance, be accomplished by creating documentation based on ISO 42010, which provides a standard for describing architectures to multiple different stakeholders [19]. A few recommended elements, and the order in which they should appear, are listed below.

- Vocabulary: Summary of terms and definitions used in the documentation. Should reference any internal handbook or whitepaper with common terms, and any standards with terms specific to the platform.
- Scope: System level (e.g. cell, station etc.), applicable departments and platform classification (e.g. in terms of production process).
- Design driving requirements: List of design driving requirements and their values for
- Essential functions: The primary function of the platform and any function sequence it has.
- Principal structure and interactions: Common structure and interactions for the platform candidate. Generic description of what each element in the structure represents and what its function is. Includes a list of primary interactions, their type (see [18]) and what the actual interaction does.
- Physical enabler and interfaces: Technical drawing (or similar) of a typical enabler. Each element of the principal structure should be detailed and concrete interfaces
- Detailed enablers for specific areas of application: Summarise the area of application (requirements, and purpose). List all applicable enablers that are to be used in the future, how they fulfil the requirements and the specific interfaces for all their elements. Include links to existing internal or supplier documentation. If there is only one area of application, this section is merged with the physical enabler section.
- Links for further reading: Links to any referenced or relevant standards and documentation for related platforms.

4.7. Govern and Maintain Platform

Platform governance refers to both the organizational structure and the information infrastructure facilitating the continued development, utilisation and maintenance of platforms. The specific organisational structure and information infrastructure will be highlight dependent on the capabilities of the existing infrastructure. As such, it is difficult to provide concrete suggestions for a specific system. Instead, general recommendations are made.

For platforms to be useful, a company must be committed to them at both higher and lower levels. The goal of using platforms must be clear at all levels, and the existence of platforms must be efficiently communicated throughout the company. It must be clear to all potential stakeholders which actors are responsible for which aspects of platform governance. In each department of the company, one person should be responsible for the overall collection of platforms used in the department, with a number of platform developers responsible for individual platforms. This person should also ensure that platforms used across multiple departments are always aligned with each other, and that systems not complying with platforms are not constructed within their department.

Platform documentation should be stored in a collective digital database so potential stakeholders, developers and user can easily access the required information, and any related information. If it is tedious for developers to check whether a certain platform exists or find its documentation, the platform will not be used.

Maintenance of platforms involves going over existing platforms, seeing if the design, decisions and reasoning from the previous iteration still hold. If not, the platform should be redesigned or scrapped if its existence cannot be justified. This also includes considering any new technologies or requirements that might affect the design of the platform.

As previously stated, this stage is an ongoing process that should not end as long as company is committed to working with platforms.

5. Discussion

As mentioned previously, the seven stages are operational guidelines, not rigid prescriptions. With approaches such as the one presented in this study, there must be room for adaption to specific cases. However, the stages should generally be carried out in the listed order.

Explicit guidelines and examples for determining criteria for identifying and selecting platform candidates is necessary in the continuation of this research. These guidelines, and a classification coding scheme facilitating classification and comparison of production systems, are the subject of forthcoming articles.

Alongside the assessment of changeability requirements, another key prerequisite for any platform development, whether green- or brownfield, is a consistent vocabulary. A common understanding on the nature and purpose of platforms, modules, changeability, interfaces and interactions is crucial to avoid miscommunication and misalignment during platform development projects [9]. This could, for instance, be addressed through an employee handbook explaining why these projects are undertaken, and what the various terms mean.

Taking brownfield platform development further requires additional context. Concrete examples of production platforms are few, and it is not something manufacturers are usually keen to share details on. Carrying out additional case studies with manufacturers where processes, tools and knowledge are tailored to the individual manufacturer can help address this issue. Experiences in tailoring the platform development process and tools will be a valuable asset in furthering research on production platforms.

6. Conclusion

In this study, a stage-gate approach to brownfield platform development has been presented. It consists of seven stages, outlining the platform development process from assessment of changeability requirements, through identification and development of individual platform candidates to documentation, governance and maintenance of platforms. The approach was developed through an evolving case study with an industrial partner.

The brownfield platform development approach outlined in this study provides an alternative to the more common greenfield approaches to platform development. Platform candidates are identified from existing manufacturing systems and equipment, after which they are, if appropriate, elevated to platform status making them reusable. This provides designers of new systems with a platform of proven, robust and reusable solutions for a number of frequent tasks in their manufacturing landscape. If no appropriate, robust and reusable solution to a task is found within the platform, a focused greenfield development project can be initiated to create a platform or module with the desired capability or technology.

Adopting a systematic platform development approach taking a manufacturer's existing production landscape into consideration could speed up the design and implementation of changeable manufacturing by lowering the barrier of entry.

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