Paving the way for changeable and reconfigurable production

Fundamental principles, development method & examples

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Preface

This book is published as part of the project "REKON – Development of Reconfigurable Production." The project is founded by the Danish Industry Foundation and is carried out by Aalborg University in collaboration with the University of Southern Denmark, Jönköping University, and the Danish Technological Institute.

The REKON project aims to develop a method and related tools to make Danish production companies reconfigurable and ensure better opportunities for faster conversion of their production through modular solutions. The project builds on research results from the last 10 years, for example within various research projects within Manufacturing Academy Denmark (MADE) on modular and platform-based production.

In the REKON project, several Danish and Swedish production companies have participated and contributed to both developing and testing the REKON method, as well as to exemplifying the tools. These are: Kamstrup A/S, Grundfos A/S, Elvstrøm Sails A/S, Vestas Wind Systems A/S, Dan-Foam ApS, Volvo Group Trucks Operations, and Ljusgårda AB. Therefore, the authors of this book would like to thank:

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- **Erika Wahlqvist, Ljusgårda AB**

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Introduction

Reconfigurability as the key to changeability and competitiveness

Many Danish production companies experience increased variety and complexity in production. In addition, the requirements for shorter time-to-market are increasing, and smaller batch sizes are needed. The REKON project aims to enable Danish production companies to meet these challenges.

Reconfigurable production is a new type of production systems designed for quick and efficient capacity adjustments, conversions, and introduction of new products. This is accomplished using modular production equipment and close coordination between the product and the production platforms. Traditionally, dedicated production systems, designed to produce a specific set of products and variants, are becoming increasingly inadequate as markets become more uncertain and product lifecycles shorten. To avoid costly and time-consuming conversions or the need for entirely new production systems, companies must shift toward reconfigurable production systems that can be easily and quickly adapted as markets and product demands change. Thus, reconfigurable production systems are key to achieving efficiency, robustness, and changeability in production.

This book is intended to pave the way for changeable and reconfigurable production. It is intended for individuals who seek to understand the basic principles of changeability, such as reconfigurability, modularity, and production platforms. It also provides knowledge on how to practically implement and enhance these principles in real-world industrial environments through specific industrial examples, a methodical approach, and relevant tools. The book features examples from Danish and Swedish companies, such as Kamstrup A/S, Grundfos A/S, Vestas Wind Systems A/S, Elvstrøm Sails A/S, Dan-Foam ApS, Volvo Group Trucks Operations, Ljusgårda AB, and Hydrema A/S.

We wish you a pleasant and inspiring read!

Chapter 1

The reconfigurable factory

Danish production companies need to produce greater product variety to satisfy the market. This requires that production must deliver increasingly different products to customers to be competitive. At the same time, there is greater demand to shorten the time-to-market due to international competition. This implies that production must decrease the time for producing a product, which encompasses activities like identifying customer needs, developing the products, preparing production, scaling up, and delivering the finished products. Finally, in recent years there has been a tendency for customers to place orders more frequently and in smaller quantities, resulting in an increase in the number of orders, while simultaneously reducing batch sizes in production. This means that companies must adapt to more changes to meet market demands than in the past.

The increased product variety and smaller order sizes, resulting in smaller production batches, require more frequent changeovers in production. This can lead to increased downtime and reduced capacity for production. Additionally, the increased variety and the more frequent introduction of new products often require companies to invest in new equipment, such as machines and tools, and, in some cases, new production systems, in order to manufacture new products. This can tie up capital and may also result in production downtime for conversion and commissioning. Together, these factors result in a reduction of the time available for creating value, an increased demand for capacity, and more frequent investments in new functions and capacity.

One of the reasons why this can be a challenge for many companies is that they tend to think of production in terms of "one product at a time," rather than considering their entire product portfolio and designing production systems that are adaptable to future products and market uncertainties.

In companies that utilize reconfigurable production, the production equipment and systems are designed to be easily, quickly, and cost-effectively modified. Through reconfigurable production, new products can be introduced by simply adjusting the existing production system, typically through the replacement of specific modules rather than developing new systems or equipment. Thus, using reconfigurable production is faster and cheaper than creating new modules and systems, as a significant portion of the functionality already exists within the system. This is possible because many companies' products often share similar characteristics and use similar production processes. When a new product generation is introduced, reconfiguration involves replacing only those modules matching processes that need change, while retaining the modules with unaffected processes, as illustrated in Figure 1.1.

Similarly, companies can leverage the ability to reconfigure production systems when capacity needs to be scaled. Often, companies build production systems with a higher capacity than initially needed to ensure sufficient capacity in case demand increases. This approach has the disadvantage of potentially running with a large unused capacity over a longer period. Additionally, this often means that, if demand increases more than expected and the existing system becomes insufficient, the only option for increasing capacity is to build another production system, thereby doubling the capacity. A factory with reconfigurable production lines can scale capacity in smaller increments because the production lines are designed to accommodate this type of change from the beginning. This is done, for example, by preparing the system to be reconfigured with faster and more automated processes at bottleneck stages or by adding more parallel processes to increase capacity, as illustrated in Figure 1.2. These advantages can only be achieved if modularity and reconfigurability are integrated into the production system design from the beginning.

Another recurring challenge for production companies that produce a large variety of products is investing in production capacity for individual product variants or specific product families. In such cases, equipment or lines are built to only produce a single product or a small number of different products, requiring investments in specialized equipment and multiple systems, meaning a dedicated production system for each product. As demand for products often changes over time, this can result in production systems not being fully utilized and having significant excess capacity. In a reconfigurable factory, common

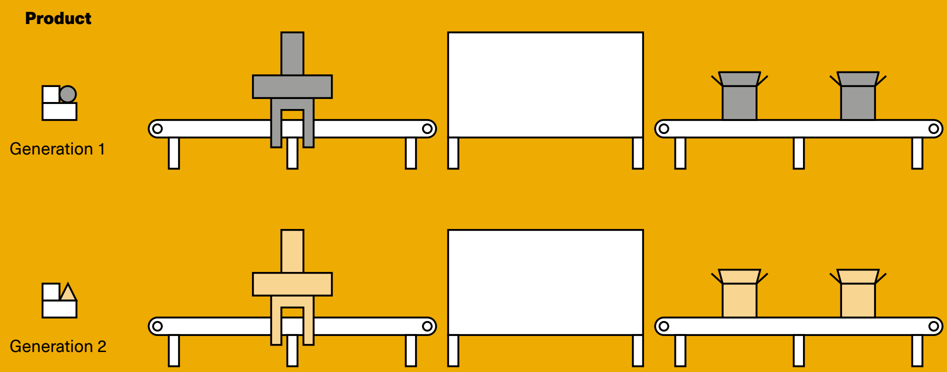


Figure 1.1. *The fundamental principle of reconfiguring to accommodate a product change.*

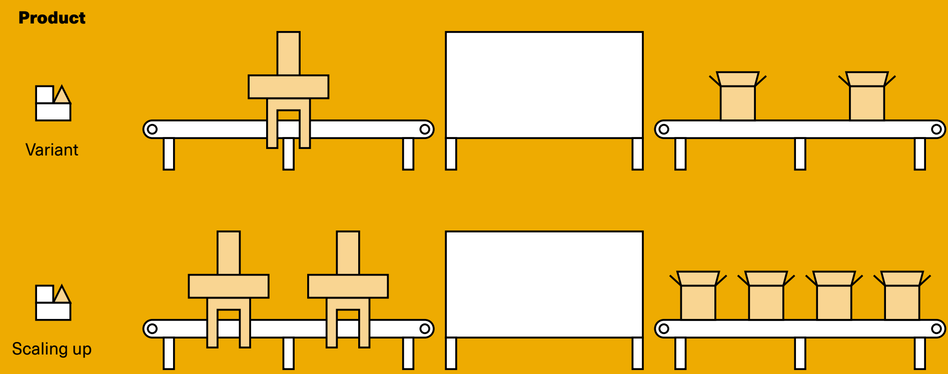


Figure 1.2. *The fundamental principle of reconfiguring to accommodate changed capacity requirements.*

features between the products and the processes needed to manufacture those products are identified. This allows us to distinguish between common processes and differentiating processes in production. The common processes match fixed modules, while the differentiating processes are built into modules that can be replaced as demand changes. This is illustrated in Figure 1.3, where three parallel lines are used to produce product A. At some point, a new product (B) is introduced, and a single line is reconfigured to produce this product by replacing a module, while the remaining two lines continue to produce product A. After some time, product A is phased out, and all lines are reconfigured to produce product B. This way, different products can "share" the capacity of multiple reconfigurable lines, rather than requiring dedicated lines for each product. This can lead to a significant reduction in the number of lines and capacity required, and less capital needs to be invested in production equipment. In the example in Figure 1.3, a traditional approach would have required six production lines (three for each product), while the reconfigurable production can meet the demand with only three lines.

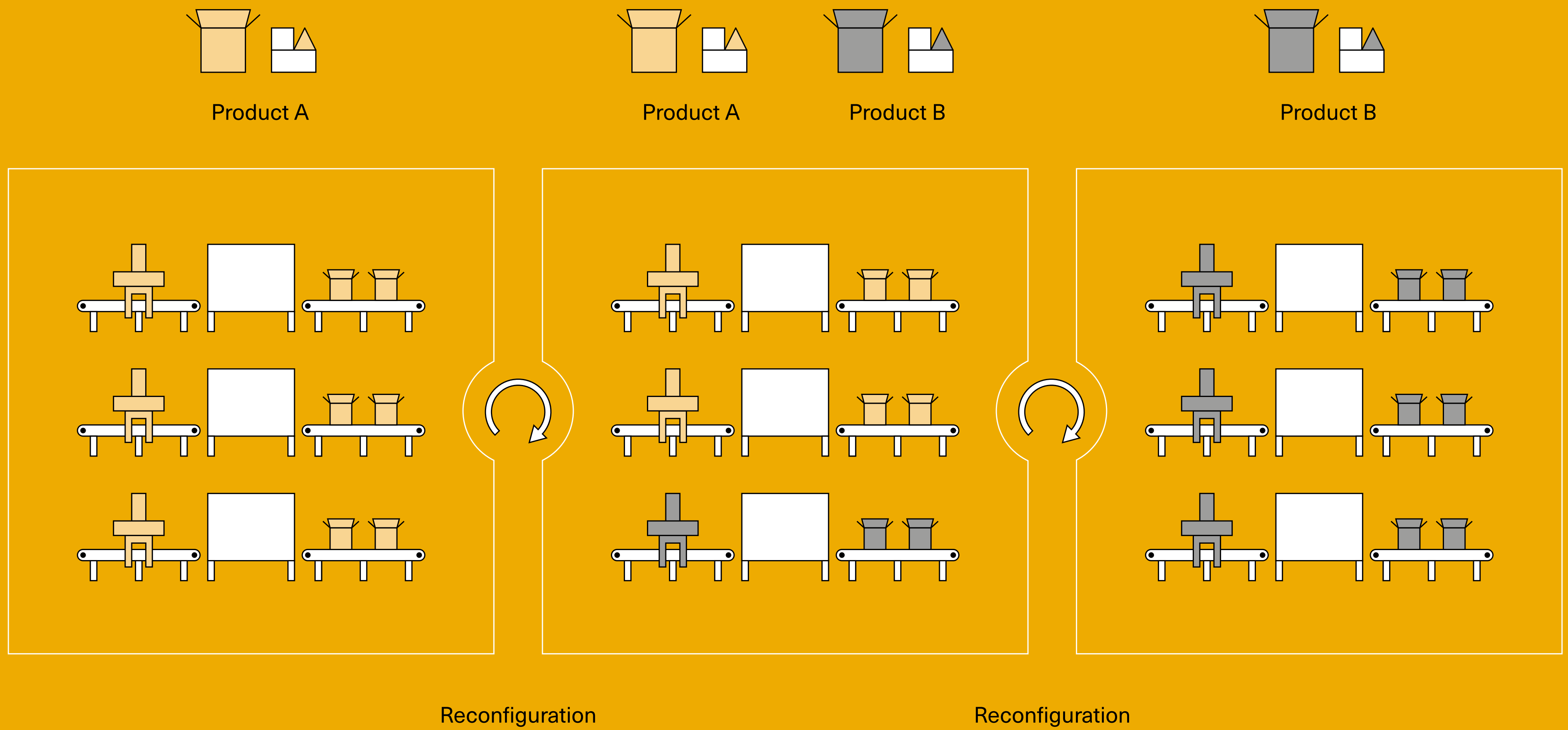


Figure 1.3. *Sharing capacity using reconfigurable production lines.*

To summarize, the reconfigurable factory is designed specifically to be easily converted when needed, whether due to a large variety of products, frequent product introductions, or changes in the product mix. However, building a reconfigurable factory requires taking reconfigurability into account as an important design requirement. The remaining chapters of this book present a series of fundamental principles, methods, and tools that can aid in the journey toward developing a reconfigurable factory.

Chapter 2

Changeability, reconfigurability, and flexibility

The well-known motto of the Ford Motor Company's founder that "the customer can have any color on his car as long as it is black" no longer applies. Whereas production companies used to focus on producing one product variant as efficiently as possible, today's and future production systems must be equipped to handle changing conditions. This means being able to efficiently produce a large number of variants, as well as accommodating regular product introductions, which cause frequent capacity changes and ramp-up periods in production. The production requirements have changed over the past decades due to societal, market-related, and technological changes and advances. In order to achieve such changeability in production, it is important to find the right combination of reconfigurability and flexibility.

Short-term and long-term production requirements

Trends in the market and changes in customer needs can create the need for changes in both products and production. Changes in regulations, advances in technology, new materials, and societal needs can all lead to the need for new or modified products. Sometimes, a company's product portfolio will change drastically, while other times it will be expanded or updated with new variants over time. In this context, a product variant can be defined as a specific kind or type of product that belongs to a product family of different variants. For example, it could be a specific car model selected by a customer. The product family is a group of product variants that have some common features, such as sports cars. If viewed from a time perspective, it makes sense to talk about product generations, which are typically defined as specific versions of products and product variants over time.

Depending on the industry and market a company operates in, product variants, product families, product generations, and production volume will change in both the short and long term. This creates changes in the overall production requirements, as well as changes in specific processes and equipment. Changes in product variants are typically short-term and involve switching from producing one variant of a product to another, for example by changing the product mix or making small customer-specific adaptations of products. Changes in production volume, meaning either upscaling or downscaling the production output, as well as changes in products, meaning introducing a completely new product or a new generation of a product family, are typically of a longer-term nature. Figure 2.1 shows how different trends in the context of the production company can create a need for variant changes, volume changes, and product changes.

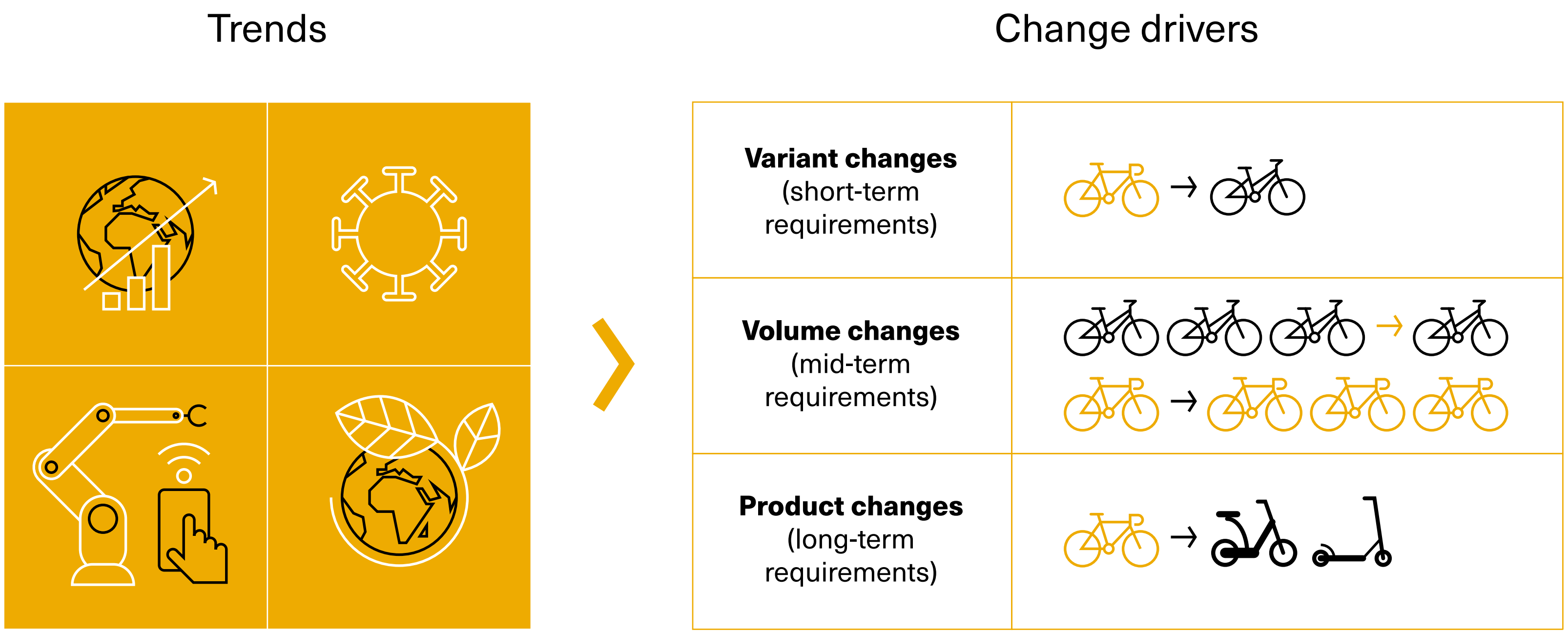


Figure 2.1. *Contextual trends affecting variants, volume, and products.*

Production paradigms

Regardless of the type of change involved, i.e., either variant, volume, or product change, it is important for the production system to be able to adjust quickly, easily, and cost-effectively to these changes. This requires the combination of both productivity and responsiveness to changes. There are two ways to achieve changeability: through flexibility or reconfigurability. Flexible and reconfigurable production systems differ from traditional dedicated systems as follows:

- A dedicated production system is typically associated with mass production, where the system is designed and optimized for a small number of product variants. This results in cost-effective and high-volume production. Here, equipment, machines, and tools are specifically dedicated to the purpose.

- A flexible production system can produce a wide variety of product variants and can easily switch between these without significant conversion time. This is possible because the system consists of equipment that only requires programming to produce a different product. Some of the most flexible machines are 3D printers.

- A reconfigurable production system is composed of modules that can be assembled in different configurations for different product variants, production volumes, or product generations. This allows the system to adapt the capacity and functionality to changing market and customer needs over time.

Figure 2.2 illustrates the differences between these three production paradigms. The dedicated production system offers high capacity for a single product group, while the flexible production system offers high functionality for different product groups. The reconfigurable production system is situated in between these two extremes, offering a combination of capacity and functionality. In theory, the reconfigurable system offers exactly the functionality and capacity needed, when it is needed.

It is certainly clear that the reconfigurable production system has significant advantages over the other two paradigms. Firstly, it reduces the risk of having either too high or too low functionality or capacity in relation to market requirements, making this system more robust against uncertainties in the market, customer needs, technological changes, etc. Additionally, it allows for cost-effective production within each specific system configuration, while also being able to change configuration as needed.

It is easy to distinguish between these three types of production systems based on the capacity and functionality characteristics. However, it is important to note that most production systems are a combination of these three types, containing processes and equipment that are to some extent dedicated, flexible, or reconfigurable. For example, a factory might possess a mix of reconfigurable production lines that have a modular structure and can change their configuration, along with flexible systems such as manual workstations, and even dedicated systems like a machine or tool built for a specific purpose. For this reason, it makes sense to consider reconfigurability and flexibility as general capabilities that can be incorporated into a production system using appropriate design principles.

The difference between reconfigurability and flexibility

At first glance, the distinction between reconfigurability and flexibility may seem like a matter of terminology and definitions, but there are important differences in the benefits and design principles of each.

Flexibility is generally defined as the ability to quickly and easily change a system or equipment (such as a machine or a tool) without significant conversion or structural changes. Thus, flexibility is predetermined and built into the system before it is utilized.

Reconfigurability, on the other hand, is the dynamic capability to adapt production by making structural changes to the system and its equipment, which provides new functionality or capacity. This often involves a period of downtime, reconfiguration, and ramp-up for the system.

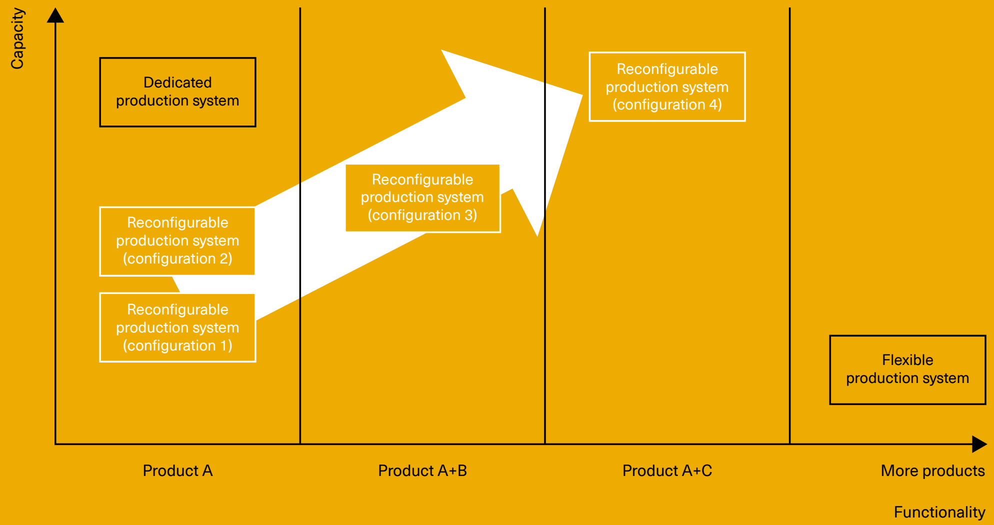


Figure 2.2 *Production paradigms.*

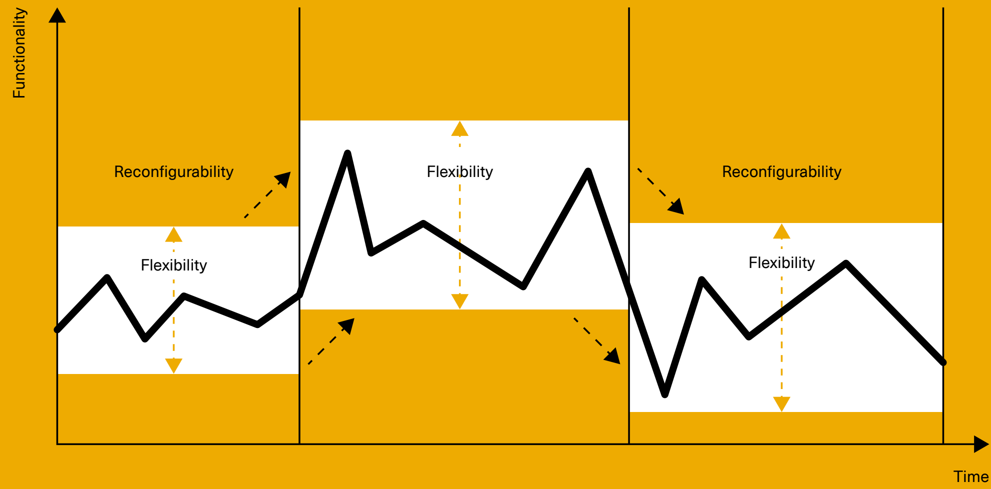


Figure 2.3. *The difference between flexibility and reconfigurability.*

Flexibility is typically used to quickly and with limited effort adapt production within a predefined range, while reconfigurability is used to change the functionality and capacity of the system to meet new or changed production requirements. The differences between flexibility and reconfigurability are illustrated in Figure 2.3 and Figure 2.4.

As mentioned, production systems will include different combinations of flexibility and reconfigurability. Flexibility represents the system's existing ability to change, while reconfigurability is the ability to change functionality and capacity. Selecting the right combination of the two is highly dependent on the context and is a question of whether to invest in a large range of flexibility from the start or in a more limited range of flexibility which instead can be adjusted dynamically over time by changing modules. The latter will be a system with higher reconfigurability and will be suitable for long-term change requirements, meaning volume and product changes. On the other hand, a system with higher flexibility will typically be best utilized for short-term change requirements, meaning variant changes.

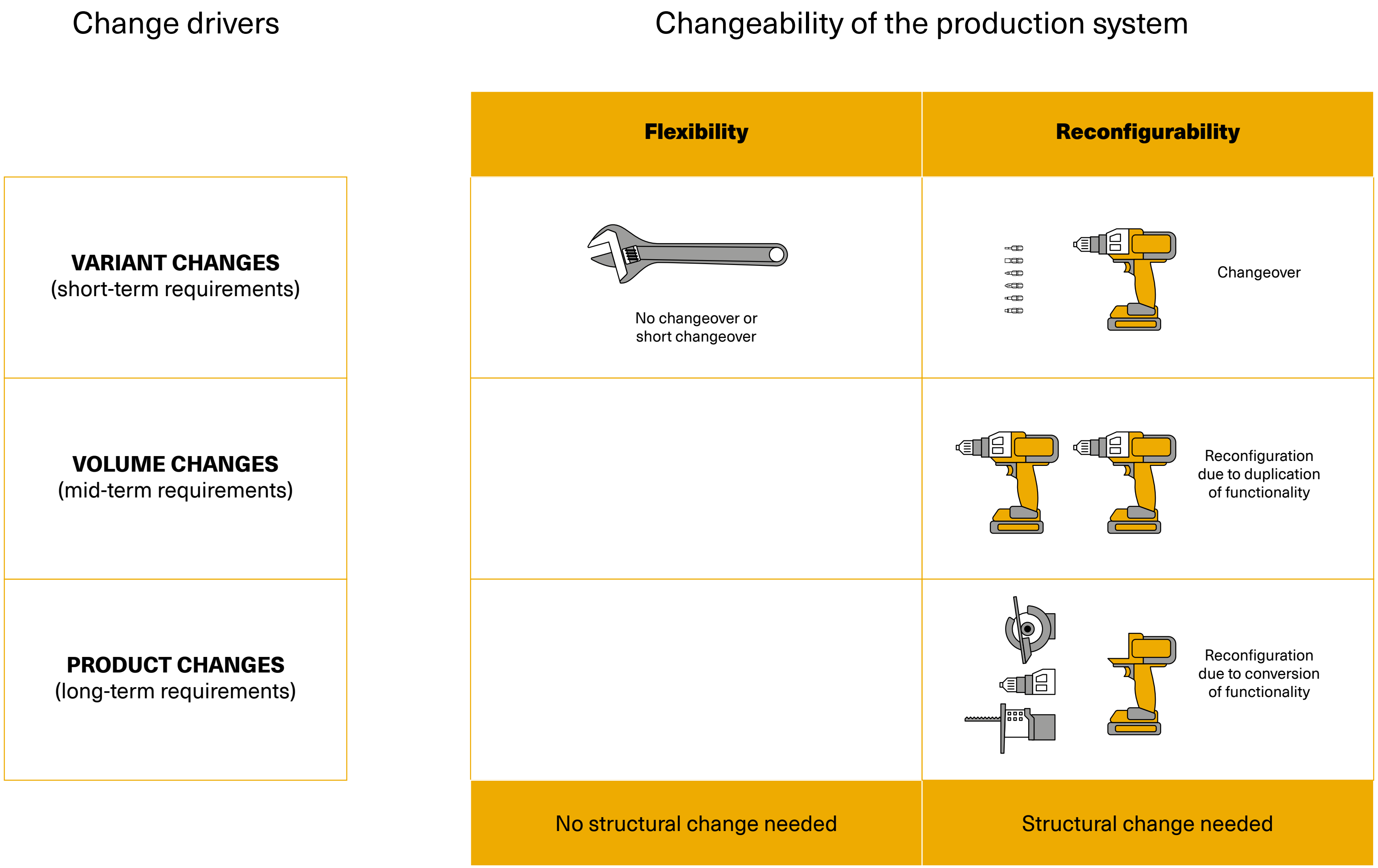


Figure 2.4. *Different levels of changeability for variant, volume, and product changes.*

Design principles for reconfigurability

To ensure that reconfigurations are carried out quickly, easily, and efficiently, there are several design principles that should be considered when designing a production system. These are:

- Convertibility: Designing the system for easy changes in functionality, meaning easy conversion of existing equipment to new production requirements in terms of mix changes or the introduction of new products or variants.

- Scalability: Designing the system for easy scaling of capacity, allowing for simple and incremental increase or decrease of the system's production capacity.

- Modularity: Designing the system to be modular, i.e., dividing the operational functions into separate, easily integrable units that can be assembled in different configurations.

- Integrability: Designing the system so that modules can be easily combined using standard mechanical, information, and control interfaces.

- Customized flexibility: The various configurations of the system are designed with flexibility that is specifically adapted and customized for the group of products or product families to be produced at the given time. This flexibility is dynamically adapted over time through reconfiguration.

- Diagnosability: Designing the system so it can easily and automatically determine its status and detect errors during its reconfiguration, ramp-up, and operation.

- Mobility: The system's modules are designed to be easily moved around, e.g., to different locations in the production system, the factory, or even between factories.

These design principles should be considered from the very beginning when designing and developing a production system. In addition, these principles can be incorporated at all levels of a production system, from the lines, cells, and workstations to the machine tools. Moreover, a reconfigurable production system makes the entire factory, and even the value chain, more changeable, because modules can be moved around the factory or between factories, achieving greater agility in the production network.

Advantages of reconfigurability

There are many benefits of developing and utilizing reconfigurability in production. Depending on the purpose of reconfiguration, these benefits can range from operational to strategic and include:

- Reduction in changeover time through rapid reconfiguration between product variants.

- Reuse of existing equipment and systems rather than development of new ones, ensuring both financial advantages and quicker reactions.

- Increased capacity utilization, as equipment and systems can be reused and configured across variants and product generations.

- Extended lifetime of production equipment and systems.

- Faster conversion of existing production to new product variants, volumes, families, and generations.

Chapter 3

Reconfigurability, modularity, and production platforms

Modularity in products has been recognized for decades as a way to increase the reuse of product parts across product variants. A common analogy used to explain this concept is the LEGO brick, which, with its simple design and standard interfaces, can be combined with other bricks in an infinite number of configurations, while the bricks are identical or very similar, i.e., the variety is low. Essentially, modularization is about dividing a company's products, systems, or processes into several smaller chunks that provide a business advantage. This advantage usually relies on the possibility to reuse standard modules across several products, systems, or processes, as well as over time. In the example of a company producing PCs, it can be easily established that a power supply in a PC covers a function that is independent of the type of PC being produced, and the customer would not gain any value from a differentiation of the power supply. In this case, the company will be able to produce different PC models with only one standard power supply, rather than needing the production of one power supply per variant of PC. This results in greater economies of scale in the purchasing or production of components, reducing the variable costs of products.

Modular products and production

A camera can be used as an example to clarify the difference between a modular product and an integrated product, as shown in Figure 3.1. A single-lens reflex camera is a very modular product because different functions are assigned to different physical components. For example, the lens can be easily replaced with one that has a stronger zoom function while maintaining the other functions, such as recording and saving images, as these are contained in another module. This provides several advantages because the product can be adapted over time and upgraded as needed by the user. A disposable camera, on the other hand, is an integrated product as all functions are combined into a single unit, making it impossible for the user to change or upgrade individual functions.

In product design, modularization involves dividing functions into distinct physical components and defining the interfaces between them. These interfaces are often standardized, allowing for interchangeable parts, like the LEGO bricks, the car engine, or computer memory, to be replaced easily. Similarly, in the production system, standard interfaces between modules allow for easy replacement when necessary, as shown in Figure 3.2.

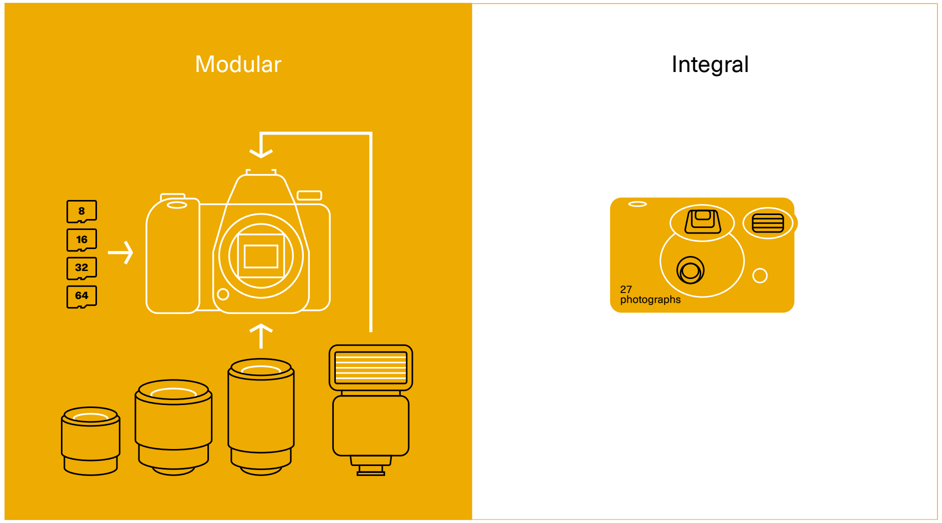


Figure 3.1. *Examples of modular and integrated products..*

Modularity in production systems is fundamental to achieve changeability supporting variant, volume, and product changes. In terms of variant changes, modularity allows production of already existing products while ensuring cost-effective conversions between them. For example, this can be done by introducing modular machine tools and fixtures that can be modified by replacing individual modules.

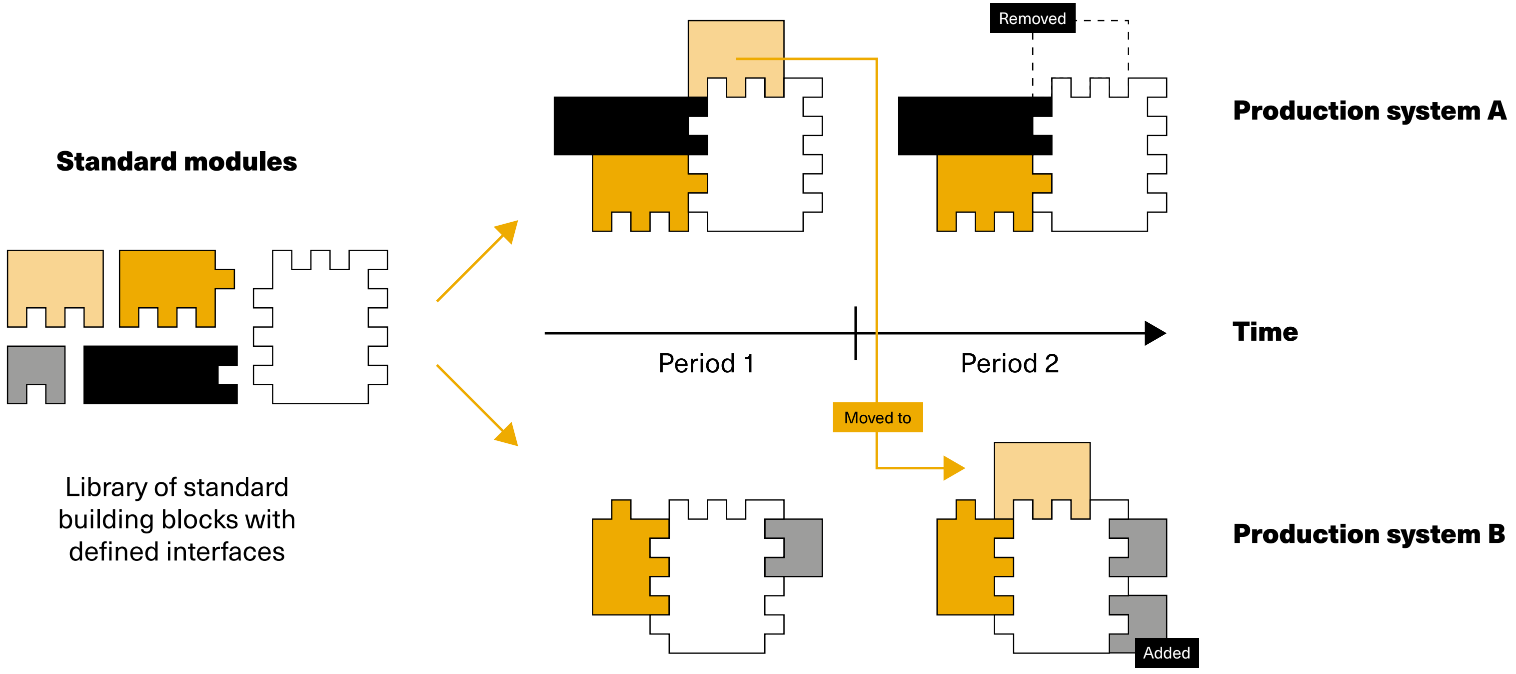


Figure 3.2. *Standard modules allow for different configurations in a production system.*

For instance, the production company Hydrema A/S developed a reconfigurable fixture for the welding of excavator arms. They were able to replace six dedicated fixtures with a single modular fixture. This resulted in a significant reduction of time spent on changeover for variant changes. Specifically, the company reduced the changeover time by 80%, as the need to remove, store, and set up dedicated fixtures was eliminated.

Developing modular machine tools and fixtures usually makes the system changeable for variant changes, i.e., short-term production requirements. Developing modularity at higher levels of production, such as modular machines, lines, or cells, makes the system changeable for volume and product changes, i.e., longer-term change requirements in production. Modular machines, lines, or cells can rapidly and cost-effectively be adjusted to the production of newly introduced products that still share common features with existing products.

Product and production platforms

A product platform is a collection of elements that are common across multiple products. These elements will often be in the form of standardized modules. A platform can also be a technology, software, or a set of several modules. Product platforms are widely used in various industries, with the automotive industry being a noteworthy example. The Volkswagen group, for instance, had successfully developed common platforms for specific car sizes in the 1990s. More recently, they introduced a scalable product platform usable for the development and production of vehicles ranging from microcars to large family cars. This scalable platform includes a set of standard “building blocks,” which can be selected and used when developing a new car. Examples of building blocks are chassis, engines, electronics, brakes, locking systems, seat systems, and air conditioning systems, i.e., parts of the vehicle that do not need differentiation, as most of the customers only need these parts to function properly. In this way, some of the activities of the development process can be “reused,” saving money and time. Thereby, only the customer-facing elements, such as the bodywork and interior, need to be differentiated, requiring the efforts of product developers.

Companies that have implemented product platforms may also develop a production platform, which is the production equivalent of a product platform. It includes standard elements that can be used to build a specific production system, such as standard robot cells, modularized fixtures, or standard conveyor systems. Using these standard elements, during the development process the production developer can reuse already consolidated and tested principles and must only allocate time to developing those components and solutions that need to be specifically designed for the new system. Overall, this creates major savings both in terms of time-to-market and of the required financial resources for the development process.

Product platforms and production platforms are interdependent. The capabilities of a new production system are closely tied to the product being produced, making coordination between product and production platform development essential. This is often called platform-based co-development.

A very simplified example of a production platform can be demonstrated with a screwdriver, as shown in Figure 3.3. A screwdriver must have different shapes and sizes to fit different types of screws, such as Torx, Umbraco, or Philips. Considering the screw as the product and the screwdriver as the production system, when developing a traditional screwdriver, every time a new screw (product) is developed, a new screwdriver (production system) must also be developed and manufactured. However, in principle, the screwdriver has basic functions that remain constant across different screw types, such as transferring torque from the handle to the screw and enabling the user to hold it with one hand. By developing a multi-bit screwdriver, where the screwdriver has a holder for different bits suitable for different screw types, it becomes possible to introduce support for new screw types by simply developing and manufacturing a new bit. In this case, the common functions across screwing tasks (transferring torque from the handle to the screw and enabling the user to hold it with one hand) reside in a platform. This approach saves both investment and time, because every time a new screw (the product) is developed, only a single component of the screwdriver (the production system) must be developed.

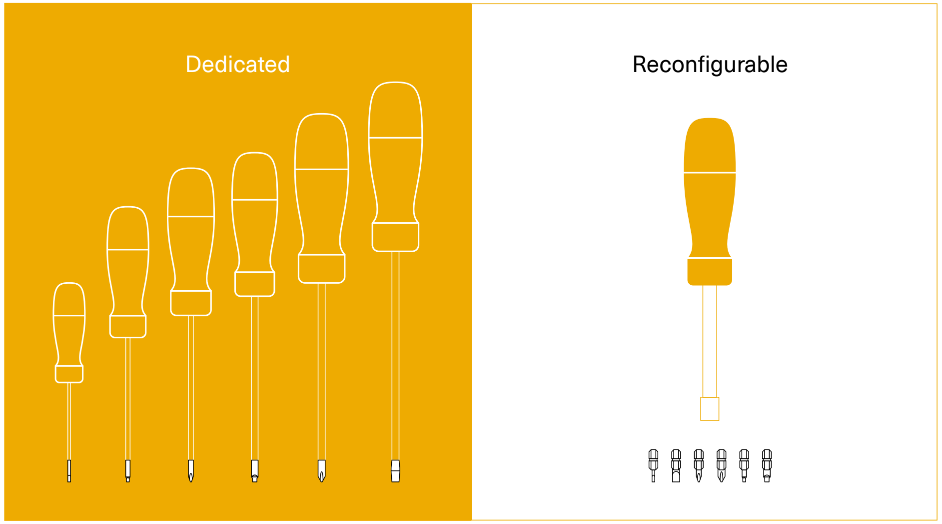


Figure 3.3. *Simplified example of dedicated and reconfigurable tools.*

Interfaces and interactions

Modularization and platform development require clear definitions of interfaces between modules, as these make it possible to use platforms and assemble both products and production systems. In reconfigurable production systems, it is also important to have standardized interfaces between products and production systems. This standardization enables production equipment to handle different products. At the same time, it allows a product to be handled by different types of production equipment. An example of this is the Volkswagen Group's use of the product platform MQB and the production system platform MPB. The company developed standardized contact surfaces between car bodywork and holding equipment, for example for holding at welding cells and handling at painting robots. Being standardized, these contact surfaces are part of the platform, and make the same production equipment able to handle multiple car models. In some cases, the platform is scalable, as the distance between contact surfaces is adjustable thanks to automatic mechanics in the production equipment, thus allowing greater reconfigurability.

Advantages of using modularity and platforms in production

Modularity and platforms in production systems provide many benefits, such as reusing optimized and consolidated designs across systems, and reusing physical equipment. These lead to faster and cheaper development of new systems, and the ability to adapt and reconfigure systems to changing needs throughout their lifetime. Modularity is essential in enabling reconfigurable production: by replacing modules, i.e., performing a reconfiguration, the production system is adapted to new needs.

Chapter 4

REKON method: Four steps to developing changeable and reconfigurable production

The development of production systems and equipment is a complex process. This process becomes particularly complex when the system must be developed to support not only production of the existing product variety or generation, but also be able to easily and quickly be reconfigured for new product families, generations, or changed market conditions. For this reason, production companies often need support to develop, implement, and utilize a reconfigurable production system. The REKON method, a simple four-step process, was designed for this exact reason, as it supports the development of reconfigurable production.

Challenges in developing reconfigurable production

A distinctive feature of reconfigurable production, as opposed to dedicated production, is that equipment can be easily and quickly reconfigured to adapt the capacity or functionality, rather than being specifically designed and optimized for just one product or a limited number of variants. This offers many benefits, including increased reuse of equipment, higher utilization of resources, longer life-time of equipment, faster changeovers, and reduced time-to-market.

Reusing production systems and equipment is not a new concept, and companies often strive to do so to save time and investments. However, there is a key difference between the ”ad-hoc” or ”random” reuse of equipment often experienced in industry, and the systematic reuse resulting from developing a reconfigurable production system. . When developing a reconfigurable system, systems and equipment are explicitly designed and developed with a focus on easy, fast, and maximum reuse across product variants and across product generations over time. In other words, production must be developed to be modular and platform-based from the very beginning. However, there are several challenges in implementing this approach, such as:

- Production systems are often developed after the new product has already been developed, or when the product development is in the final stages. In addition, production development is often optimized to ensure the lowest production cost of the current design, without considering future changes in the product or future needs.
- Developing a reconfigurable system requires scenario-based approaches, where it is essential to analyze and evaluate the system’s robustness against uncertainty and future product changes.
- Evaluating and quantifying the need for reconfigurability can be complex, and many design choices must be established, evaluated, and compared.
- Design principles for reconfigurability, including convertibility, scalability, modularity, integrability, customized flexibility, diagnosability, and mobility, must be considered in the development of all technical solutions and for both physical and logical elements.

When developing a reconfigurable production system, it is important to not only consider traditional design elements, such as type of equipment, layout, automation level, flow, system integration, capacity, facilities, and quality assurance, but also consider potential equipment configurations, modularization, and solutions for minimizing reconfiguration time. This highlights the need for a new method to aid in the development of reconfigurable production systems.

The REKON method

The REKON method can be used to guide and support the development of reconfigurable production systems and overcome the aforementioned challenges. This method is the result of more than 20 years of research within reconfigurable production and production development. In addition, the method has been tested and enhanced in collaboration with several companies and research institutions. The examples in this book are drawn from the companies that participated in testing and improving the method.

The REKON method comprises four steps. As outlined in Figure 4.1, these steps are analogous to those included in many universally applied development processes: clarification of needs, concept development, detailed design, and implementation and utilization. This means that the REKON method is not a completely new way of conducting development compared to the usual steps companies take in developing production systems, but rather an addition that incorporates reconfigurability throughout the entire process. It is important to note that each of the four steps in the method includes a specific number of activities. These activities are supported by the REKON tools. Both activities and tools will be discussed in greater detail in the following chapters.

Therefore, the REKON method is meant to be integrated into existing development processes and projects within production companies. Any company can follow the activities of the REKON method and adapt the associated tools to its context. The method supports the development of reconfigurable equipment and systems with extended lifetimes beyond the initial product or product family.

The four steps of the REKON method are sequentially and methodically arranged. Step 1 is the clarification of the need for reconfigurability. This step clearly identifies the need for reconfigurability by considering not only short-term change requirements in production, but also longer-term change requirements, including potential changes and uncertainties in product, mix, and volume. Other activities included in this step are assessing the current level of reconfigurability, clarifying reconfigurability potentials, and establishing a business case. The outcome of step 1 is a list of technical and economic requirements for the system that guides the following step. In step 2, the two connected activities are identifying and analyzing product characteristics and variations, and mapping interfaces between products and production. In addition, concepts for technical solutions are generated for both system and modules. Finally, a systematic and economic evaluation of the concepts is also conducted to determine the appropriate level and type of reconfigurability. The outcome of step 2 is further developed in step

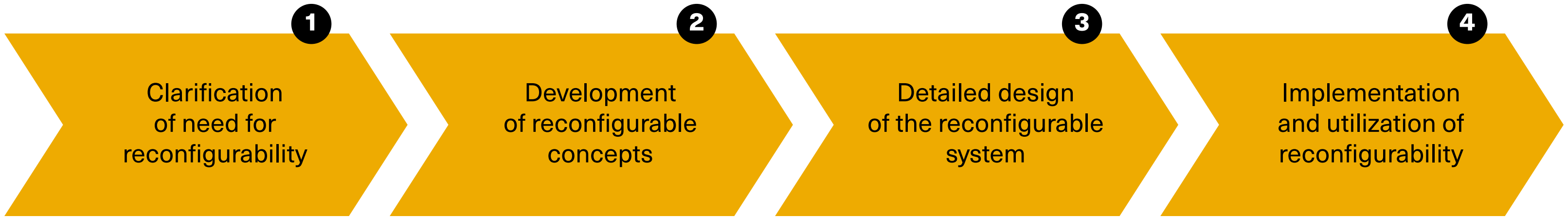


Figure 4.1. *The four steps of the REKON method.*

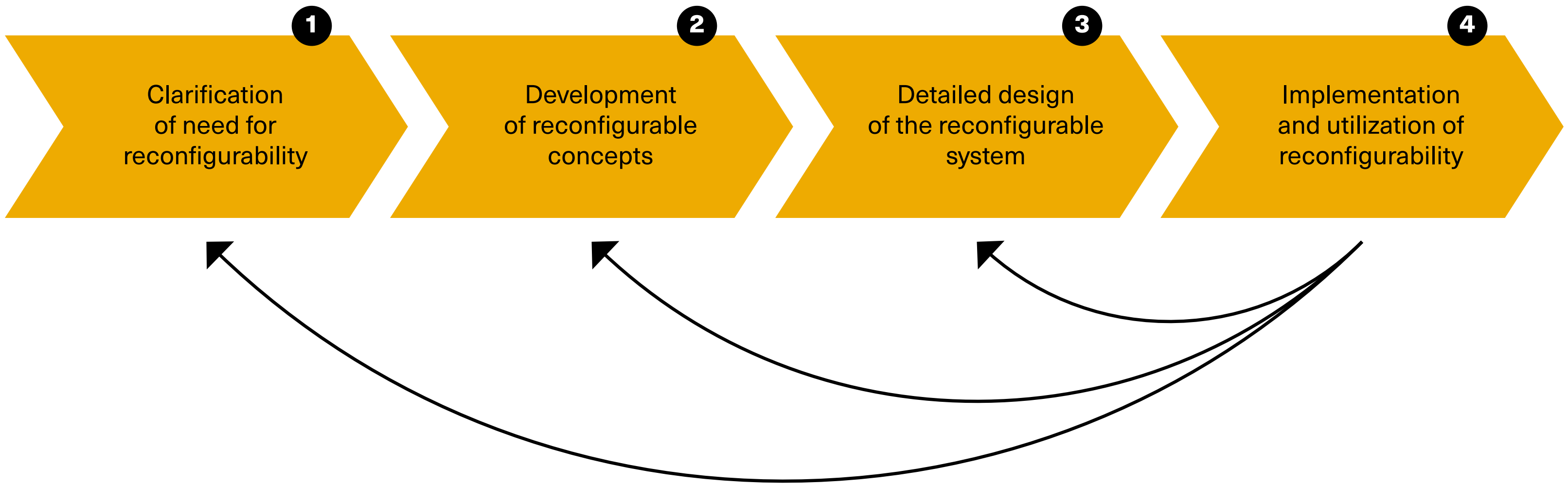


Figure 4.2. *Iterations between steps of the REKON method.*

3, where specific modules and system interfaces are designed, evaluated, and documented. In step 4, the system is implemented, run, and reconfigured. Thus, this last step is more focused on the implementation and exploitation of reconfigurability rather than design. After the system is operational, step 4 supports continuous evaluation of the system's reconfigurability and performance in relation to the product range and market. If necessary, a reconfiguration is triggered - this may require designing new modules or simply switching to an already tested configuration. Depending on the extent of the reconfiguration, the process loops to one of the previous steps, as shown in Figure 4.2. Thus, steps and loops support both the development and utilization of reconfigurability in the long-term.

Steps, activities, and tools

The uniqueness of the REKON method is that each step comprises a series of activities that are supported by various REKON tools. As can be seen in Figure 4.3, the REKON tools serve as the foundation for carrying out the activities in each step.

The tools are the backbone of the REKON method, and there is a specific tool for each individual activity of the method and at each step. Examples of the REKON tools include the method for mapping and identifying requirements for reconfigurability (Appendix 1.1, page 62), the model for evaluating total costs for different reconfigurable production system concepts (Appendix 1.3, page 64), and the method for predicting configurations of the system based on product characteristics (Appendix 4.2, page 76). All REKON tools are based on research and have been tested and documented in various production companies. Figure 4.4 illustrates the complete REKON method including activities and associated tools for each step.

Use of the REKON method

The REKON method is used for the development of production systems. The method not only considers the physical elements of the system, such as equipment, machines, and tools, but also its logical elements, such as sensors, control systems, MES, and ERP, as well as people, operators, and management. The changeability and reconfigurability of a production system are not limited to the hardware and equipment, but also include the other elements of the system. For example, in a partially manual assembly system, reconfigurability can be improved by using more flexible tools and better planning, prediction, and execution of reconfiguration. The REKON method can be applied to a wide range of situations, including the design of new production equipment, and the redesign and improved utilization of existing equipment, as well as different levels of a production system such as an entire assembly line, a specific workstation, or even a specific tool.

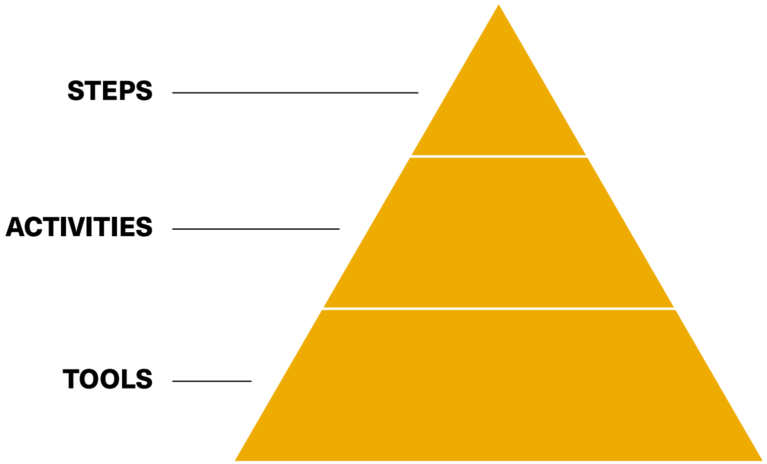


Figure 4.3. *REKON tools as the foundation for carrying out activities and steps.*

An important message in this book is that there is no "one-size-fits-all" solution that can be applied to all situations. Instead, changeability, which includes a combination of reconfigurability and flexibility, may be incorporated into different aspects of production. These aspects also vary greatly depending on industries and specific needs. In other words, reconfigurability is a capability in a production system that can be designed and realized in many different ways. The REKON method is presented as a way to develop the best approach in each specific business context. This book includes cases and examples from very different companies to illustrate the use of the method and associated tools in different contexts. These cases had different starting points, requirements, and focuses for the development of reconfigurable production. For example, in some cases the REKON method supported the development of new production systems - in other cases, the method was implemented to increase the reconfigurability of existing systems or equipment. In the Dan-Foam ApS case, the REKON method was used to support the development of a completely new system, while in the Kamstrup A/S case, the method was used to both map the existing level of reconfigurability and identify areas needing changes. Finally, the following case of Volvo Group Trucks Operations illustrates how a company succeeded in embedding the steps and activities of the REKON method into its existing production development process.

Figure 4.4. *A complete overview of the REKON method, including specific steps, activities, and tools.*

Case:

Development of reconfigurability at Volvo Group Trucks Operations

New products are introduced at a rapid pace, and product life cycles have become shorter. Therefore, the production systems of the future must be more adaptable and able to handle several products at the same time. The vision at Volvo Group Trucks Operations (Volvo GTO) is to have reconfigurable assembly systems that can be more easily adapted to new product introductions and changes in production volumes. Tobias Högfeldt, production engineer at Volvo GTO, says: "This means that we can increase volume and capacity by adding more modules, and this also means less investments at a time. Demand will increase over time, but we want to avoid making a significant investment at once. We also have a great need to adapt quickly to new technologies in relation to electric trucks. Before, we made changes to platforms. Today, we must produce completely new platforms – in half the time."

At Volvo GTO, the implementation of reconfigurable production meant rethinking how production is designed. This includes not only the development of technical solutions that are modular, but also getting the organization on board with the new long-term thinking for production development. Thus, the existing approach to developing production systems was entirely reviewed and rethought, with the aim of ensuring the inclusion of reconfigurability. Therefore, to create a reconfigurability mindset and introduce new guidelines for production development, Volvo GTO introduced, among other things, the following changes:

- A changed way of mapping current equipment and production lines to identify current levels of dedicated, flexible, and reconfigurable equipment. With the introduction of this systematic method, the future requirements and expected scenarios in terms of the product portfolio can be quickly compared with existing production capabilities, thus identifying focal points for design in existing processes, as well as increasing equipment reuse and modularization. In addition, Volvo GTO could set goals and KPIs for reconfigurability in the future.

- A new approach to evaluate and analyze investments in production equipment, which considers to a greater extent the potential changes and reconfigurations that a production line could undergo. With this new approach for the evaluation of costs and investments in production, it has become possible to quantify the benefits of reconfigurability.

- A new approach to balance assembly lines after reconfigurations, which can be used, for example, when a new product variant is introduced or when an existing line needs to be reconfigured.

An important learning from Volvo GTO's work toward developing reconfigurable production was that it was not solely a matter of being able to develop modular technical solutions: it also required that the entire approach of the company towards the design of production activities and supporting tools was rethought, including in cooperation with equipment suppliers.

Chapter 5

Evaluation of reconfigurability

Evaluation is essential in the development of reconfigurable production systems. It involves both economic and technical analysis supporting design decisions. In essence, evaluation and design are interconnected and crucial components of production development. Evaluation is integrated in the REKON method throughout the development process. Initially, in step 1, the focus is on the economic evaluation of reconfigurability, and an initial business case is created to clarify the potential for reconfigurability before solutions are made in later steps. In step 2, multiple reconfigurable production concepts are evaluated from both an economic and technical standpoint, leading to the selection of a concept for detailed design in step 3. In this step, different design choices are evaluated and selected. Finally, in step 4, continuous evaluation during operation is necessary to analyze the system's capacity and functionality and determine any necessary reconfigurations based on product and market requirements. Figure 5.1 summarizes all the evaluation activities in the REKON method's four steps. In this chapter, details regarding the economic and technical evaluations in the method are provided.

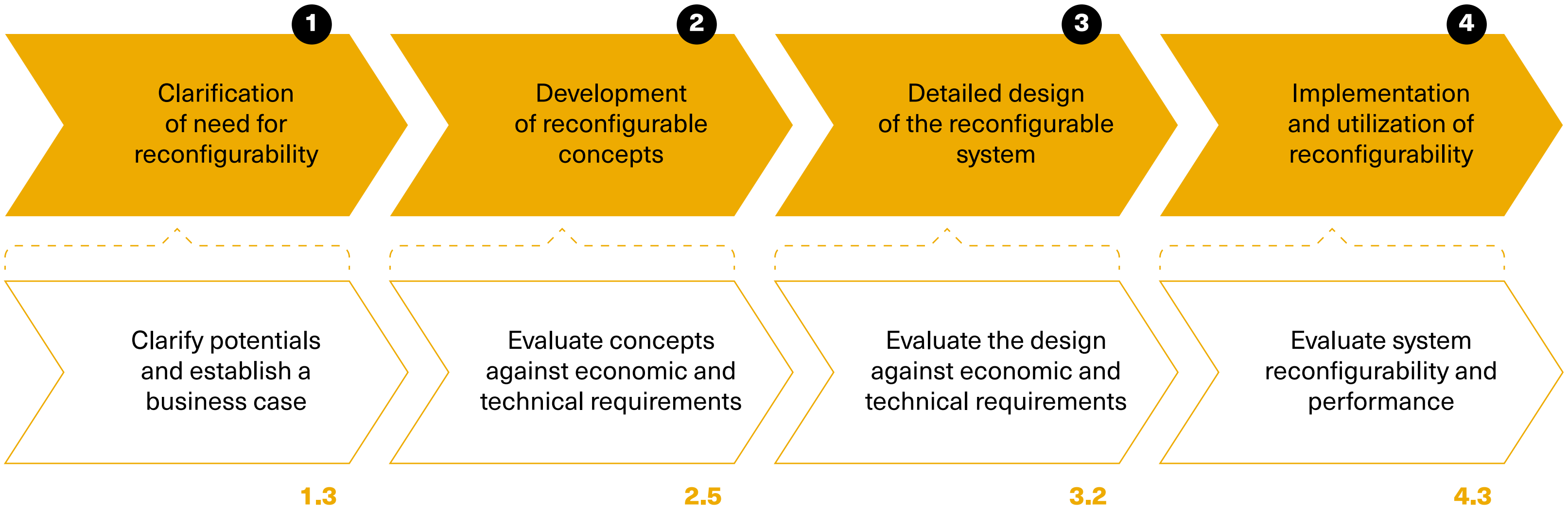


Figure 5.1. *Evaluation activities in the REKON method's four steps.*

Evaluation and development of reconfigurability

Reconfigurability is a novel concept for many production companies, and it is, therefore, necessary to justify and evaluate the implementation of modularity and reconfigurability in production before starting the actual development project. Afterwards, the development project itself needs continuous evaluation, leading to design revisions. Both economic and technical evaluation are considered in the REKON method.

Economic evaluation examines the profitability of alternatives and is used to drive investment in production. This evaluation secures financial commitment and managerial support.

Technical evaluation tests and validates solutions, typically through simulations. This evaluation ensures that the right design decisions are made and that the right technical solutions are used to develop reconfigurability.

Technical and economic evaluations are particularly important at the start of the development process, as early design decisions determine approximately 80% of the development and investment costs for a production system.

Evaluation is an ongoing process throughout the REKON method, becoming more detailed and specific as the design progresses. Overall, decisions related to reconfigurability must be evaluated in each step, as follows:

- Step 1: In this step, it is important to justify the investment or increased development cost in a reconfigurable and modular production system compared to traditional, dedicated production systems. This typically requires creating a business case that accounts for the benefits of a reconfigurable system, such as an initial assessment of the impact on changeover time, equipment investment, capacity utilization, and product introduction time. At this stage, there might be limited knowledge about the specific system design, but a general understanding that reconfigurability is beneficial.

- Step 2: In this step, more knowledge is gained about potential production system concepts that can achieve the required changeability identified in step 1. Different combinations and degrees of flexibility and reconfigurability, as well as different technical solutions, must be considered. For example, a fixture that is highly flexible and can accommodate many future product variants versus a modular fixture that requires structural modifications to adapt to future variants. Both economic and technical evaluations are necessary to determine which concept should progress to detailed design.

- Step 3: In this step, the design of the production system will be highly detailed, allowing for a more specific technical and economic evaluation. It is important to assess the technical solutions, in the form of modules and interfaces, in relation to existing and future variants. It might also be necessary to verify the technical solutions and simulate a reconfiguration of the production system.

- Step 4: In this step, it is necessary to simulate reconfigurations of the system, and continuously evaluate whether the system's capability and operation are appropriate or whether a reconfiguration is needed. If so, it will be necessary to determine which configurations are sufficient to meet product and market requirements. Continuous evaluation is important to ensure the system remains capable and functional.

Reconfigurable production systems can be challenging to justify from an economic perspective. They often require higher initial investment and development costs compared to traditional, dedicated systems. However, in the long term, the investment can pay off as system modules can be reused and replaced as changes occur in the production mix, due to changes in the product portfolio and market demand. The typical cost development for reconfigurable and dedicated systems is illustrated in Figure 5.2. Traditional methods of economic evaluation, such as net present value models, may not be sufficient to handle the complexity and capture the long-term benefits of reconfigurable systems, as they are usually limited to a single product and a shorter time horizon. Therefore, a modification of traditional methods and tools is necessary.

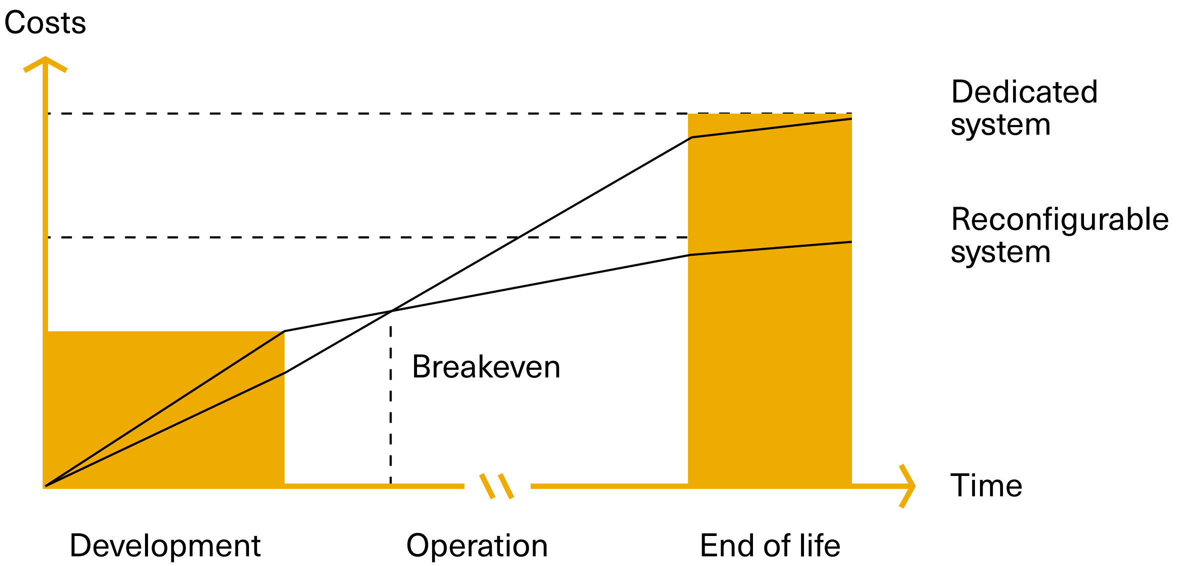


Figure 5.2. *Illustration of costs as they would typically emerge in the reconfigurable and dedicated production system over the lifetime of the system.*

Economic evaluation of reconfigurable production

When conducting an economic evaluation for the development of a reconfigurable production system, four key aspects should be taken into consideration. These aspects focus on evaluating whether a specific set of solutions, in a context of uncertainty, will yield a gain. Uncertainty is a crucial factor to consider, as reconfigurable production has its greatest advantages in its ability to adapt easily to new market requirements and products. Factors such as uncertainties in market penetration, timing of product introductions, product mix, and future variants should be taken into account when evaluating the necessity of a reconfigurable production system.

Typically, multiple aspects (see Figure 5.3) comprise the economic evaluation of a reconfigurable system, each of which may contain several parameters. The relevance of these should be considered based on the specific case and then specified or estimated using historical data, current information, and future forecasts. These parameters are included as inputs in a calculation or model, the choice of which depends on available resources and the deadline for the results. In step 1, the degree of detail is limited, but as the development project progresses, the degree of detail in the solution design increases and, thus, also the need to include more choices and possible outcomes. This can also increase the reliability of the results. Therefore the economic evaluation is largely incremental,iterative and is closely tied to the design process itself.

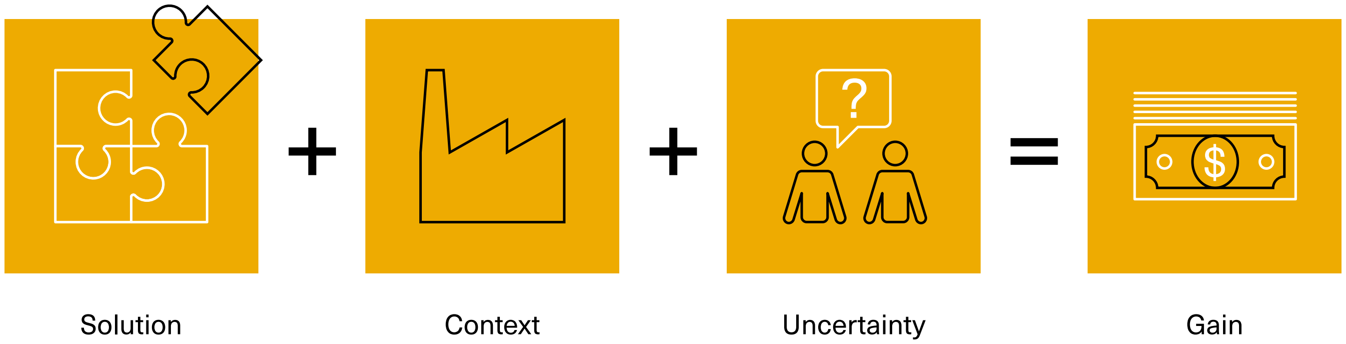


Figure 5.3 *Relevant aspects to consider when evaluating a reconfigurable production system.*

The solution addresses options for the production system, which can be evaluated at different levels of detail. At a simple level, the system can be considered as a black box, focusing on estimated investment cost and time for reconfigurations. This is typically done in step 1 of the REKON method. At a more complex level, in step 3, the system architecture is broken down into modules, where it is specified which are used, reused, and varied between configurations. This additional level of detail allows for differentiation of parameters according to different combinations of configurations - these become necessary when the complexity of the solution is increased in the detailed design. This necessitates specifying investment costs for each individual module for different configurations, as well as replacement time for the modules between configuration options. Additionally, it allows for inclusion of acquisition time, production system lifetime, and maintenance time for each individual module, as well as the time needed to bring the system's production capacity to the desired level. Regardless of the level of detail, it is recommended to calculate the relative gain against the current production system.

The context refers to the production environment in which the solution must operate and interact. It includes parameters that are not directly determined with the solution, such as investment costs for acquiring the remaining production and handling equipment. In addition, wages and material costs associated with production, as well as storage costs, are included. Operational parameters such as workload, staff, working hours, space capacity, and delivery time also need to be considered.

Uncertainty refers to parameters within the solution or context that have a degree of uncertainty or variance, which can be represented in a set of scenarios or deviation ranges. The inclusion of uncertainty is important because evaluations deal with the future, which can be difficult to predict. To strengthen the decision-making rationale for selecting a solution, it is necessary to expand the possible range of outcomes beyond what is immediately expected, in order to increase the validity of the evaluation. Uncertainty typically affects factors such as product variety, introduction time, life cycle, order size, and system utilization over time. Additionally, uncertain resource availability and material supply, which have changed in recent times across industries, may also be relevant to consider.

The gain refers to the economic and operational parameters that must be evaluated for solutions and is based on identified potentials. Economic parameters typically include: (i) investment costs for the production system and modules; (ii) operational costs of production capacity underutilization, reconfigurations, and maintenance; and (iii) earnings due to faster time-to-market. Operational parameters can include utilization of production capacity and production system lifetime. Regardless of the choice of parameters, it is recommended to use discounted present value and compare differences in the results between solutions.

Economic models can be developed in different ways based on the above principles. In this book, two examples are presented: a simple calculation model (Appendix 1.3, page 64) intended for step 1 of the REKON method and a more detailed calculation model (Appendix 3.2, page 73) intended for step 3 of the REKON method. Both models are based on the four aspects: solution, context, uncertainty, and gain, but at different levels of detail. In the detailed model, the system architecture is known, meaning that costs can be specified at module level, while in the simple model the system is seen as a black box. The simple model can also be used in step 2 for activity 2.5, but, as noted in Chapter 7, in this case the use of the ranking hierarchy and matrix tool (see Appendix 2.5, page 70) is recommended. Using the simple model in step 2 would allow for a qualitative assessment of both economic and technical aspects, which is often necessary in concept evaluation.

Technical evaluation of reconfigurable production

In this book, the term technical evaluation covers various aspects that are already evaluated and simulated in traditional production development, such as process flow, changeover time, cycle times, ergonomics, operator movement, and performance of specific processes. These technical aspects of the production system must be evaluated and verified regardless of whether it is a traditional, dedicated production system or a reconfigurable production system.

For reconfigurable production systems, simulation is particularly useful because the production system dynamically changes over time. Discrete event simulation can be used and offers the following advantages:

- Possibility to analyze the production system and the current configuration (step 4). This can help in identifying bottlenecks and determine the optimal way to meet new needs through reconfigurations. It also allows testing new configurations before implementation.

- Possibility to test and evaluate multiple designs (steps 2 and 3). This allows for verification and selection of designs based on different criteria.

- Increased confidence that a reconfigurable production system is a good idea (step 1) by simulating a modular system versus a dedicated system.

There are many types of software available for building simulation models to support the development and utilization of reconfigurable production systems. The selection and use of specific software depends on availability, price, and required expertise at the company. Therefore, this book does not recommend specific software, but Appendix 4.3 provides an overview and comparison of some available options for simulating reconfigurable production systems. In the REKON method, it is recommended to use simulation in step 4 and specifically in activity 4.3, but it can also be beneficial in step 1, 2 and 3.

Case:

Reconfigurable production increases the changeability of the global production network at Vestas Wind Systems A/S

Vestas Wind Systems A/S (Vestas) faces fierce competition in terms of costs per megawatt, driving a race for the faster introduction of larger and larger wind turbines. The market for wind turbines is global and requires tailor-made turbines for different wind and environmental conditions, spanning both land and water, which further increases variance in the product portfolio. Additionally, the pressure for localized production is increasing due to requirements from customers as well as rising costs and restrictions on transportation. To meet these demands and requirements, Vestas must continuously adapt the production mix across internal and external factories in the global production network. This results in an increasing number of conversions of capital-intensive production equipment, which requires important reinvestment due to the current dedicated approach to production development.

With the REKON method, Vestas focused on clarifying the need for reconfigurability (step 1), designing modular production equipment, and evaluating the business potential of the generated designs (step 2). The clarification of need for reconfigurability included mapping historical trends and expected future changes to the dimensions of product components, as well as the ability of the factories to handle these changes. This provided insight into the potential for equipment reuse, and an overview of reinvestment costs in production equipment. The subsequent design phase focused on breaking down the construction of the production equipment into a modular architecture, considering both functional requirements and limitations in the value chain. Thus, the company developed a conceptual design of reconfigurable production equipment based on the modular approach. Vestas conducted a conclusive technical evaluation of the selected design, focusing on validating the system architecture and optimizing the reconfiguration process, while also conducting an economic evaluation throughout the development process. The focus of the economic evaluation was a calculation of capital and operational costs for the global production network, enabling the selection of a design for a new component family based on informed decisions.

Case:

Simulation supports vertical farming of the future at Ljusgårda AB to effectively scale production

In a small town in southern Sweden, there is a farm which, at first glance, is very different to traditional notions of crop cultivation. Ljusgårda AB (Ljusgårda) is an example of the agriculture of the future, where all cultivation takes place indoors and is key to the company's vision of making Sweden self-sufficient in fresh lettuce by 2025. This vision naturally requires a focus on improving and continuously scaling up production capacity. However, effectively scaling up production capacity is not a simple task, as it requires knowledge of where and how to begin to have the greatest possible effect. To help with this, the company has, with the REKON method, investigated the possibility of using the principles behind reconfigurable production to achieve better scalability and changeability in their production.

Although growing vegetables may sound simple, the production system is complex. Therefore, a detailed simulation model of the existing production system was built. The model was built using Siemens' Tecnomatix plant simulation software. Through several scalability analyses, the bottleneck in the system was identified. The results of the analyses showed that by simply adding two more packaging machines to the production line, production capacity could be increased by 40%. In addition, the simulations also provided valuable insights into ways to improve scalability in both the short and long term. The analyses carried out in Ljusgårda are similar to the evaluation typically conducted through simulation in step 4 of the REKON method.

Chapter 6

Step 1: Clarification of need for reconfigurability

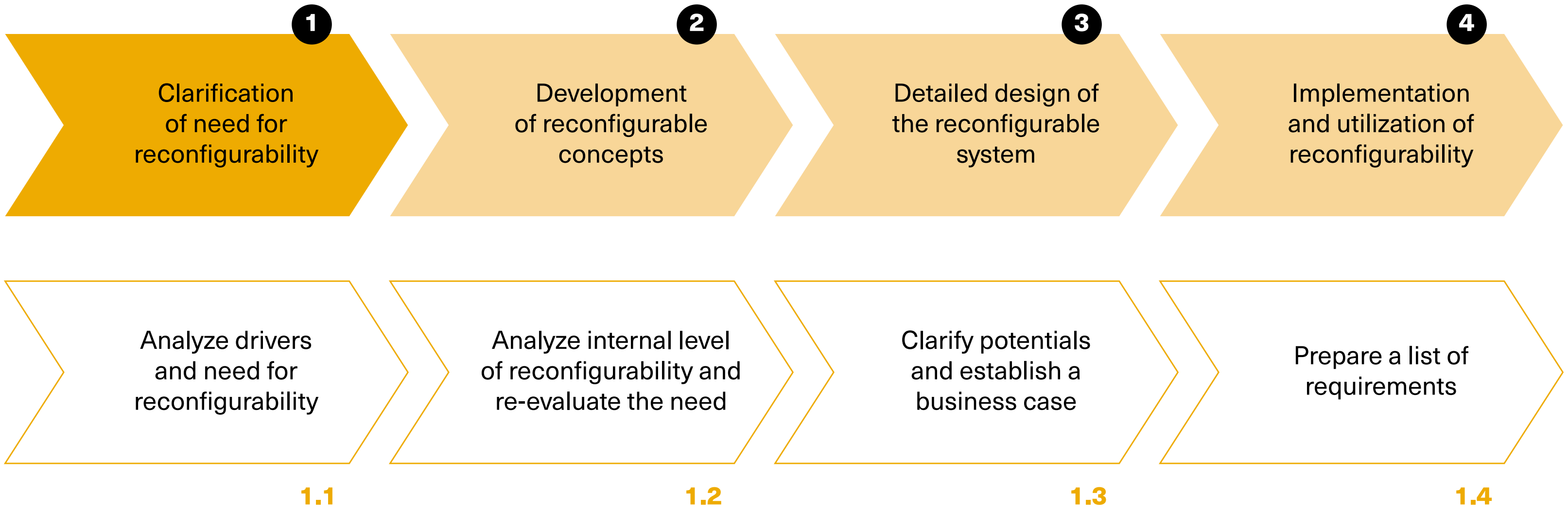


Figure 6.1. *Activities in step 1 of the REKON method.*

Step 1 of the REKON method is the clarification of the need for reconfigurability. This step examines whether changeability and reconfigurability are relevant and valuable for a company. It also examines the specific reconfigurability requirements in the company and its production. This step is crucial, as the need for reconfigurability in a production system depends on company-specific "drivers," such as market requirements, product portfolio, and customer demand, as well as various strategic goals in production. Specifically, step 1 is important because:

- Not all companies, production lines, or workstations need the same level of reconfigurability. The need for reconfigurability will vary depending on the industry, market requirements, and specific challenges. For example, a company that manufactures customized products and experiences an increase in product demand and market uncertainty may be more interested in achieving higher levels of reconfigurability in production.

- Relevant production stages where reconfigurability is necessary must be identified. This must be done based on the specific variation in the form of different tasks, tools, and general requirements that the production stages face. Furthermore, the existing and potential performance of the system should be assessed.

- The potential for reconfigurability must be investigated and mapped. This often involves the establishment of a business case, which clarifies and quantifies the potential for developing a reconfigurable production system.

To support this, step 1 of the REKON method includes four activities, which are illustrated in Figure 6.1.

Activity 1.1: Analyze drivers and need for reconfigurability

With this activity, the so-called "drivers" are identified, analyzed, and converted into need for reconfigurability. This activity clarifies the level of reconfigurability needed in the company for a specific group or family of products. In this context, a driver is any factor, is any factor, particularly related to product development, that will cause or require changes in one or more production systems. For example, replacing a polluting material with a sustainable one in a product's bill of materials (BOM) would often be a driver for changes in the company's production systems. Drivers can be both internal and external factors that impact a company's products and production, now or in the future. Drivers can also change over time and lead to different requirements for the production system throughout its life cycle. There are four categories of drivers:

- Product-related drivers relate to the development of products. These include changes to the BOM or to product architectures, and the introduction of new materials.

- Technology-related drivers impact both product development and production, such as new process technologies or new production possibilities.

- Market-related drivers relate to the customers, such as changes in market preferences and needs, increased individualization of products, and societal changes.

- Strategy-related drivers are typically driven by the company and include decisions on market offerings, outsourcing, and location decisions.

There are countless drivers that can affect production and result in a specific need for reconfigurability. To simplify the identification process, it is recommended to focus on one or more product families.

Once identified, these drivers need to be linked to the need for reconfiguration (as also introduced in Chapter 2):

- Need for variant changes – these are typically short-term change requirements, such as switching from one product variant to another.
- Need for volume changes – these are usually mid- to long-term change requirements, including increasing or decreasing production capacity periodically or permanently.
- Need for product changes – these are usually long-term change requirements, such as introducing a new product generation or product family.

The REKON screening tool for assessing the need for reconfigurability aids the identification of drivers and allows us to link the drivers to the need for reconfiguration.

As summarized in Figure 6.2, the first activity in step 1 ensures that external and internal drivers are screened and translated into requirements for reconfigurability.

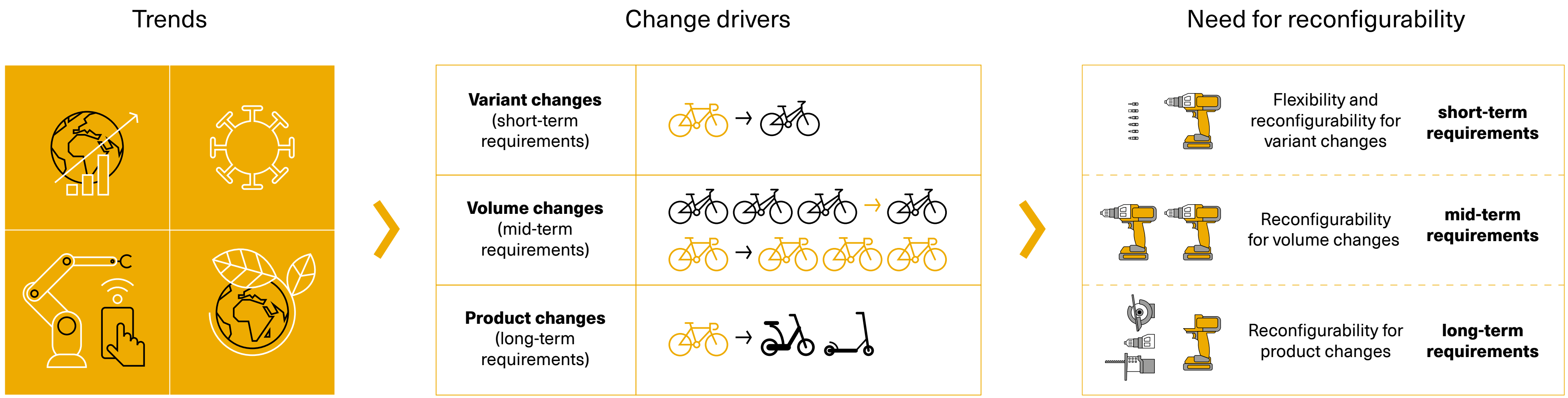


Figure 6.2. *The connection between the company's context, drivers, and need for reconfigurability.*

Screening tool for assessing the need for reconfigurability

A tool to visualize short-, mid-, and long-term requirements for reconfigurability in production systems. It is an Excel-based questionnaire that comprises 33 questions related to the various drivers and their potential impact on production. When completing the questionnaire, the user can differentiate the answers for specific areas in production, map current and future requirements, and foresee the need for reconfigurability.
It is recommended to use the questionnaire as a basis for discussing requirements for changes in production and to select one or more product families as a basis for the analysis.

>> *Read more about this REKON tool on page 62.*

Activity 1.2: Analyze internal level of reconfigurability and re-evaluate requirements

This activity depends on whether the aim is to develop a completely new production system from scratch or to improve an existing one. If a company is developing a new product and cannot reuse existing equipment (a so-called greenfield project), this activity is not needed. However, if the company has the potential to use existing equipment or needs to increase its changeability (a so-called brownfield project), this activity will be carried out to examine the capabilities of the existing production systems. Activity 1.2 helps to identify where increased reconfigurability is needed and creates the basis for refining or re-evaluating the requirements identified through activity 1.1. This activity requires an assessment and quantification of the existing reconfigurability for selected production stages. This is done with the REKON screening tool for assessing the reconfigurability of production.

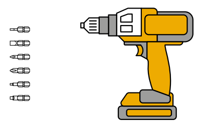
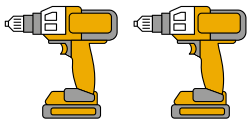
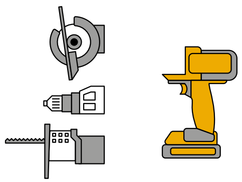
Screening tool for assessing reconfigurability of production

A tool to assess the current level of reconfigurability in production. The screening is based on a delimited area of production, in accordance with the product families selected in activity 1.1. Through a series of questions that are structured as an Excel tool, the company gets an assessment and visualization of the existing level of reconfigurability.

>> *Read more about this REKON tool on page 63.*

Activity 1.3: Clarify potentials and establish a business case

With this activity, potentials for reconfigurability are clarified, and a business case is established. This involves the economic evaluation of the investments and development efforts to either increase or develop reconfigurability in production, including expected costs and benefits. This economic evaluation has been detailed in Chapter 5. In step 1, uncertainty around decision variables is high, and the design is not yet known. For this reason, it is important to map overall benefits such as efficiency, changeover time, number of variants that can be produced, volume, and investments, and compare them to costs. An example of a comparison between a dedicated solution and a modular solution, as well as the quantification of various advantages, can be seen in Figure 6.3
In addition, the REKON business case tool can be used to establish a business case.

Need for reconfigurability		
	Flexibility and reconfigurability for variant changes	**Short-term requirements**
	Reconfigurability for volume changes	**Mid-term requirements**
	Reconfigurability for product changes	**Long-term requirements**

Potentials of reconfigurable production in relation to dedicated production systems	
Cost vs. benefits	Lower changeover time Lower changeover costs Smaller feasible production batch sizes Efficient accommodation of product variety
Cost vs. benefits	Higher capacity utilization Reuse of equipment and processes
Cost vs. benefits	Shorter time-to-market for products Lower product introduction costs

Figure 6.3. *Potentials of a modular and reconfigurable solution versus a dedicated solution.*

Business case tool

A tool for the quantitative economic evaluation of potentials through a simple Excel-based calculation model. The model compares and evaluates the total cost of production setups and can be used to compare a dedicated setup with a reconfigurable setup. The model requires overall information about the evaluated production setup, and about demand and uncertainty. It generates a discounted present value of capital and operational costs. The model also uses Monte Carlo simulation to handle uncertainty. This tool can also be beneficial for activity 2.5 in step 2.

>> *Read more about this REKON tool on page 64.*

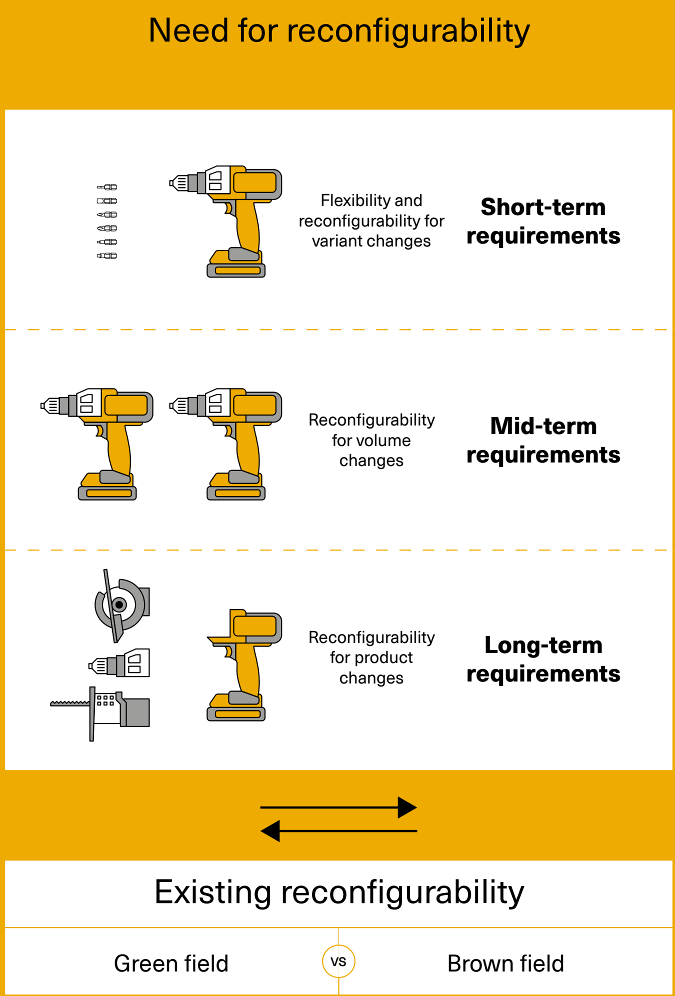
Activity 1.4: Prepare a list of requirements

With this last activity in step 1, a list of economic and technical requirements for the new reconfigurable production system or equipment is prepared. The list of requirements should directly relate to the three types of need for reconfigurability, as exemplified in Figure 6.4. These requirements are the basis for designing and evaluating concepts and for the detailed design in later steps.

Example of list of reconfigurability requirements

An overview of economic and technical requirements that could be considered.

>> *Read more about this REKON example on page 65.*



	Economic requirements: Product	Economic requirements: Production	Technical requirements: Product	Technical requirements: Production
Short-term requirements	**Product** • Cost of existing variety	**Equipment** • Changeover cost	**Product** • Number of variants	**Machine** • Changeover time • Lot size dimension
Mid-term requirements	**Product** • Cost of volume changes	**Systems and facilities** • Training cost • Scalability cost • Facility cost	**Product** • Expected volumes per variant	**Systems and facilities** • Utilization of tools • Utilization of machines • Utilization of facilities • Training time • Machine reconfiguration time
Long-term requirements	**Product** • Introduction cost • Cost of expanding variety	**Systems and facilities** • Design cost of additional modules • Training cost • Reconfiguration cost • Facility cost	**Product** • Time to market • Inspection time • Rework time	**Systems and facilities** • Reconfiguration time • Ramp-up time

Figure 6.4. *Examples of economic and technical requirements in relation to the need for reconfigurability of production.*

Case:

Identification of potential for reconfigurability and focus area at Dan-Foam ApS

Dan-Foam ApS (Dan-Foam), Denmark's largest mattress company, develops and manufactures products for Tempur. The company offers premium mattresses, adjustable bases, pillows, and other sleeping products. However, like many other companies, Dan-Foam faces an increasing demand for product variety. Rune Kjær Holtzmann, production support & continuous improvement manager at Dan-Foam, says: "It will definitely be an advantage to shift to flexible and modular production to better adapt our production systems to future needs."

The expanding product portfolio and increased variety and complexity of Dan-Foam's products prompted the company to consider how to improve production to accommodate these changes. Although the company was able to easily indicate mattresses as a critical product family, the complexity of the production process made it challenging to understand how decisions in the product development phase would impact production. Therefore, the company started with the first step in the REKON method.

In relation to the mattress product family, Dan-Foam used the screening tool for assessing the need for reconfigurability to analyze drivers over different time horizons and determine the need for reconfigurability in production. The analysis of short-, mid-, and long-term change requirements revealed that short- and mid-term requirements, related to variant and volume changes respectively, create the need for reconfigurability in the production of mattresses. This analysis made it possible to identify at which stages of production, considering changeovers and capacity adjustment, reconfigurability would be beneficial.

Dan-Foam, in collaboration with a technology supplier, developed a concept for a new reconfigurable production line. Using standard modules, the new line reduced changeovers and made production volume adaptable to different levels of demand. In addition, the company was able to replace two existing production lines with the new one.

Chapter 7

Step 2: Development of reconfigurable concepts

Based on the requirements and the potential for increasing the reconfigurability of the production system identified in step 1, step 2 of the REKON method focuses on developing and evaluating different design concepts. This is done through the five activities in step 2, as illustrated in Figure 7.1.

After completing these five activities, the company will know the specific need for increased reconfigurability and have generated and evaluated the best conceptual design to achieve this. It is important to note that the development process may differ depending on whether a new production system (greenfield) is developed, or an existing system is modified (brownfield). The activities are generally identical across both the scenarios, but there is a higher degree of freedom ingenerating design concepts for greenfield projects, as there are no existing systems to consider. In contrast, brownfield production development is limited by past design choices for the production system, which constrains possible design concepts.

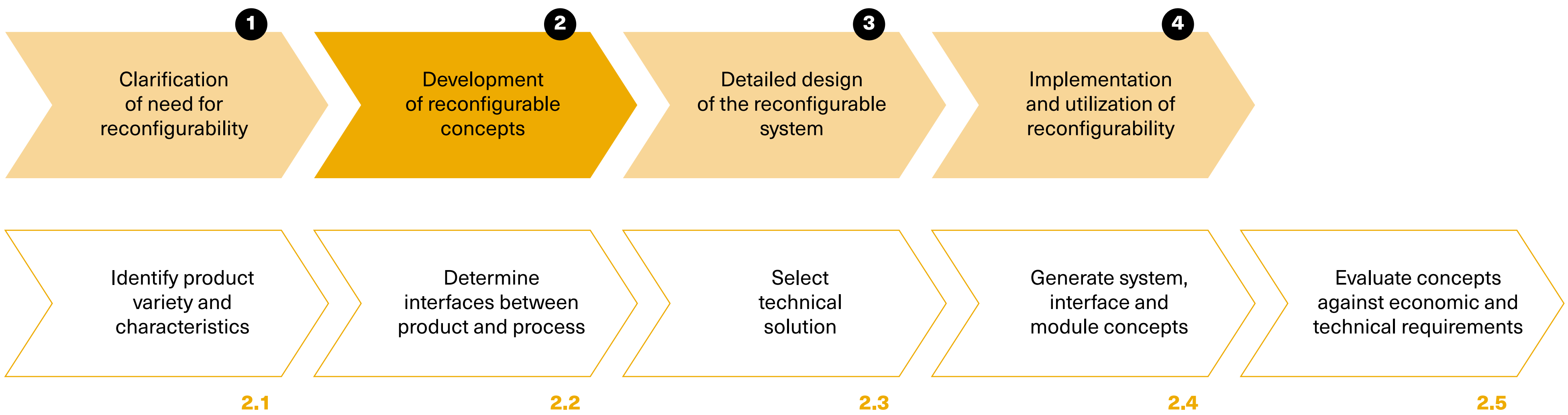


Figure 7.1. *Activities in step 2 of the REKON method.*

Activity 2.1: Identify product variety and characteristics

This activity identifies potential areas in the production system and processes that need reconfigurability based on product characteristics. This can be done by first analyzing the products produced in the production system and examining how they differ from each other. This activity is supported by the product variant master tool.

In this analysis, it is important to consider whether it is technically feasible to produce the differentiated products effectively. It is also relevant to identify unnecessary variety - for example, customers might not value differentiation of specific components or modules. Avoiding unnecessary product variety might lead to the development of product and production platforms, resulting in a more cost-efficient solution.

Product variant master

A simple graphical way to visualize product structures. Consists of two elements: a "part-of" hierarchy and a "kind-of" hierarchy, which illustrate the generic product structure of a product family (including modules and components) and the variants of those modules and components, respectively. This provides an overview of the variation and standardization of components and modules in a product family.

>> *Read more about this REKON tool on page 66.*

Activity 2.2: Determine interfaces between product and process

After analyzing product variety with activity 2.1, this activity focuses on the production side, specifically on the capability of the production processes to accommodate the desired product variety. Understanding the limitations of the production system in relation to desired product variety is essential for deciding how to improve it. In practice, this can be accomplished by first mapping the production processes that the products in the analyzed product family go through. Then, as illustrated in Figure 7.2, a mapping can be made between the product characteristics, identified in activity 2.1, and the production processes that relate to these characteristics. This will provide insight into the critical interfaces between product variants and production processes and whether the production processes can meet the requirements set by the products or not.

Any differences between product requirements and production process capabilities will indicate where production improvements are necessary. The degree of difference will also indicate whether it is relevant to focus on increasing the flexibility or reconfigurability of the production processes. This will have a significant impact on later choices of technical solutions. The overview of the processes' capabilities will also provide insight into any processes, where dedicated solutions could be advantageous. This activity is supported by the REKON changeability mapping tool. This tool can be used to analyze specific processes to create the basis for the development of concepts for the reconfigurable production system.

Changeability mapping tool

A method to identify changeability needs in a production system. It consists of four steps and includes the analysis of important product characteristics, the mapping of relevant production processes, the analysis of the relationships between product characteristics and production processes, and the identification of impacts from introduction of new product variants. This tool provides an overview of the process capabilities necessary for accommodating existing and expected future product variety. The overview also forms the basis for identifying where in the process dedicated, flexible, and reconfigurable solutions will be preferable.

>> *Read more about this REKON tool on page 67.*

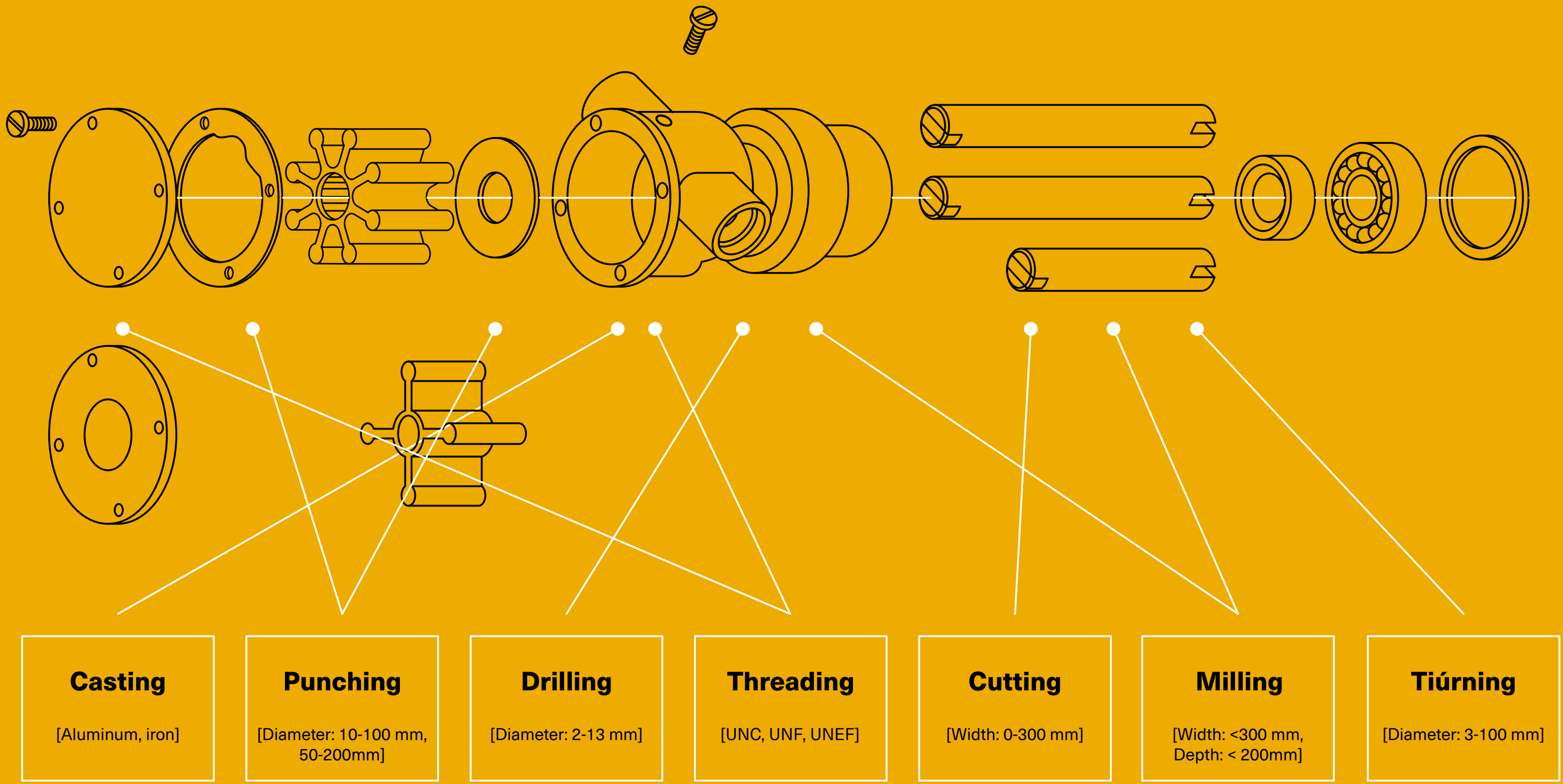


Figure 7.2. *An example of how components in a product relate to production process capabilities.*

Activity 2.3: Select technical solutions

In this activity, a thorough assessment of available technical solutions is made to determine which one is most suitable for fulfilling the identified need for reconfigurability. Generally, several technical solutions could accommodate a specific need. Therefore, it is important to establish criteria to evaluate and rank them. Company-specific economic and technical criteria are important to consider in this analysis. Moreover, when developing a concept for a reconfigurable production system, the design principles introduced in Chapter 2, such as modularity, scalability, or convertibility should also be included. The REKON catalog of reconfigurable solutions can provide inspiration for this activity, where different technical solutions are associated with design principles for reconfigurability.

Catalog of reconfigurable solutions

Today, there are numerous suppliers of flexible and reconfigurable solutions, e.g., tools, material handling, etc. The solution catalog can be a useful resource during the development process, offering inspiration and information on various commercial and prototype solutions. It includes both hardware and software solutions at various system levels.

>> *Read more about this REKON tool on page 68.*

Activity 2.4: Generate system, interface, and module concepts

Once technical solutions have been selected, the focus shifts to creating various system designs and module concepts that meet the need for increased reconfigurability. The generation of module concepts, based on combinations of technical solutions, can be facilitated by use of expert knowledge. Often, however, it is favorable to use so-called “module drivers” to aid in this process. These drivers can guide different companies with different needs in designing modular production systems that align with their specific strategic goals. Table 1 lists common module drivers related to production system design. It is important to note that the 11 module drivers in Table 1 are not exhaustive and there may be additional company-specific drivers.

Category	Module driver	Description
System development	Geometric integration and precision	For products requiring high precision in the assembly of sub-components, grouping them into one module can be beneficial. This allows for isolating critical production equipment in one process. By separating precision-critical components and processes from less precise ones, the higher costs associated with tighter tolerances can be limited to one or a few modules in production.
	Function sharing	A production resource used by multiple products can be the foundation for creating a module. Reusing a process or resource across product variants can increase the utilization of this resource.
	Process conditions and distance	Processes requiring special conditions can be grouped into a module. For example, processes that require specific temperature or environmental conditions should be placed in proximity in a production module.
Localization of change	Function stability	Some product functions are not expected to change in future generations, so the corresponding production processes often do not need to change either. By isolating these static functions in a module, it becomes possible to reuse these production modules in the future, thereby reducing development costs.
	Technology evolution	Product functions and related processes may be expected to change, as technology advances in future product generations. By grouping process functions that are likely to be affected by this development into a module, the impact on the rest of the production is limited.
	Planned product changes	Product or process changes are sometimes planned and intentional. By isolating processes affected by these changes in a module, the rest of the production is protected from costly changes when new variants are introduced, or higher volumes are required.
Variety and standardization	Common function	A function required across multiple products can lead to the development of standard modules for the associated production processes, resulting in lower development costs and increased economies of scale in production.
	Different specification	Different product functions across product variants may require a wider range of process capabilities in production. These flexible processes could be isolated in modules to limit the extent of changes required in production when switching between product variants.
Manufacture of production equipment	Supplier capabilities	Processes that require highly specialized production technology that is only available from suppliers can be isolated in a production module. This limits the impact of such specialized processes to a single module, reducing the complexity of the production system and the number of processes where suppliers are responsible for development.
Maintenance and environmental impact	Service and maintenance	Designing production processes where functions that are typically subject to wear and tear are designed as modules allows for quick replacement rather than prolonged downtime while repairs are conducted.
	Environmental impact	Concentrating pollutive production processes in separate modules enables more targeted actions to reduce the environmental impact of these processes.

Table 1: *Generic module drivers for the development of modular and reconfigurable production systems.*

Module drivers are also utilized in the REKON tool named "modular function deployment for production". By applying this tool, one or more conceptual designs of a modular production system can be generated. The next step is to determine which of these designs best meets the requirements for reconfigurability identified in step 1.

Modular function deployment for production

Modular function deployment for production is an extension of the well-known method for product design. The method consists of five steps that guide the process of creating a conceptual design for a modular and reconfigurable production system. It focuses on how to design modular production systems considering product requirements, strategic goals for products and production systems, and supports the evaluation of the quality of the generated designs.

>> *Read more about this REKON tool on page 69.*

Activity 2.5: Evaluate concepts against economic and technical requirements

This last activity focuses on evaluating the generated system and module concepts, as all concepts will not be equally feasible for the company. While some aspects of evaluating a modular production system are common to the evaluation of traditional systems, they also differ in other areas. The evaluation of modular production systems should also investigate the complexity of the interfaces between modules, meaning assessing how easy it is to change module design or change modules in the system. Furthermore, the evaluation needs to assess the suitability of degree and type of reconfigurability in relation to future product changes, both expected and uncertain.

In activity 1.3, a business case tool was introduced. The same tool can also be successfully used for activity 2.5, using the more detailed information obtained at this stage. Otherwise, a company may choose to use a qualitative approach for this evaluation. If a qualitative approach is preferred, using the REKON tool "ranking hierarchy and matrix" is advisable. With this tool, different types of economic and technical criteria can be ranked, based on the company's needs. The best concept for reconfigurability is then clarified based on the higher-ranking criteria.

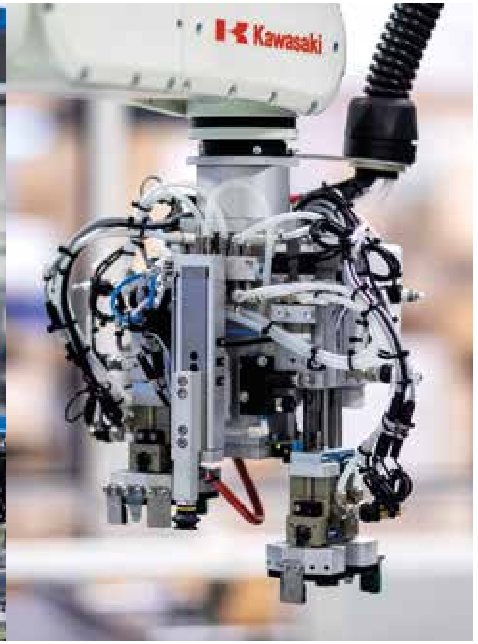
Ranking hierarchy and matrix

A tool for qualitative evaluation of concepts, considering both economic and technical criteria. The tool generates a ranking of criteria. It is efficient, user-friendly, and leverages existing company preferences. To aid in selecting the best concept, the ranked criteria are used in a matrix for simple comparison of concepts.

>> *Read more about this REKON tool on page 70.*

Case:

Kamstrup A/S maps production and products to create an overview of the production capabilities and a basis for more modular production



Kamstrup A/S (Kamstrup), a world-leading manufacturer of intelligent metering solutions for energy and water, has its head office in Stilling in Denmark, where there are also three factories – one producing water meters, one producing heat meters, and one producing electricity meters. In addition, Kamstrup has recently opened a factory in Atlanta in USA. Overall, Kamstrup has 1,500 employees in 23 countries and sells products in more than 90 countries.

Kamstrup is facing challenges due to a large growth in sales, many product variants, and increased unpredictability in sales of different variants. This has made changeability extremely important for the company. To handle these challenges in the most efficient way in production, Kamstrup is exploring the use of modular principles. Among other things, the company desires to use, reuse, and share standard modules and equipment across production lines and potentially across factories, which could lead to increased capacity utilization, increased resilience, and faster and less costly development of equipment for new lines and products. However, to increase the reuse of equipment and know where modular solutions make sense, it is necessary to create an overview of existing processes and equipment in production, as well as determine their relationship to product variants and product characteristics.

Therefore, Kamstrup joined the REKON project and implemented step 2 of the REKON method, focusing on the identification of product variation and characteristics (activity 2.1) and the determination of interfaces between product and process (activity 2.2). The company used the REKON changeability mapping tool in one of the factories in Denmark in order to investigate how to start creating an overview of equipment, processes, and lines in all their factories, as well as to know which product variants could be produced where, and which conversions or reconfigurations are necessary. This was especially relevant to form a basis for identifying processes and equipment that could be reused and shared, to drive the introduction of modules and platforms in the future. Kamstrup is currently working on further applying this mapping method and on generating an overview of equipment, processes, and lines, which is valuable and cost-effective to implement, execute, and maintain.

Chapter 8

Step 3: Detailed design of reconfigurable system

At this stage in the development of a reconfigurable production system, the most promising concept has been identified. Specifically, it has been determined how reconfigurable the system must be, the general approach for achieving this, and the overall design parameters that must be used. In step 3 of the REKON method, the focus is on translating this system concept into a detailed design that meets the technical and economic requirements established in step 1. As shown in Figure 8.1, there are three activities in step 3.

It is important to note that through the documentation of designed modules in activity 3.3, consideration is given to how the generated system and module designs can be reused in future solutions. The result of the activities in step 3 will be one or more verified and documented designs that can be implemented in existing or future production lines and contribute to a more reconfigurable production setup.

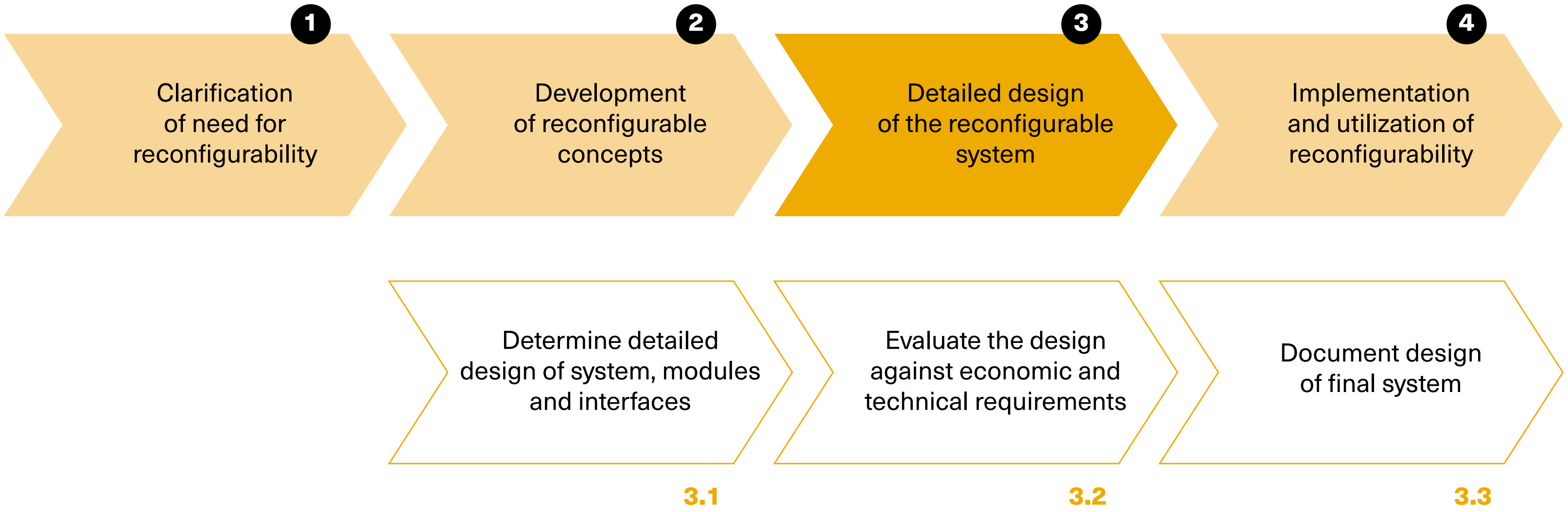


Figure 8.1. *Activities in step 3 of the REKON method.*

Activity 3.1: Determine detailed design of system, modules, and interfaces

Bringing a design concept to reality, requires its conversion from rough sketches to precise CAD drawings, including the specification of tolerances and the selection of standard components and interfaces. This is illustrated in Figure 8.2.

It is important to note that the process of creating detailed designs for a reconfigurable production system is similar to that of traditional production systems. However, in the design process of a reconfigurable production system, focus is on assessing how design decisions can potentially affect the reconfigurability of the system. For example, a module that is designed to be movable needs lightweight materials to make its relocation easier, while a module designed to be able to easily switch functions needs simple and fast mechanisms for assembly to reduce changeover times. An example of a fully reconfigurable production system is the AAU SmartLab.

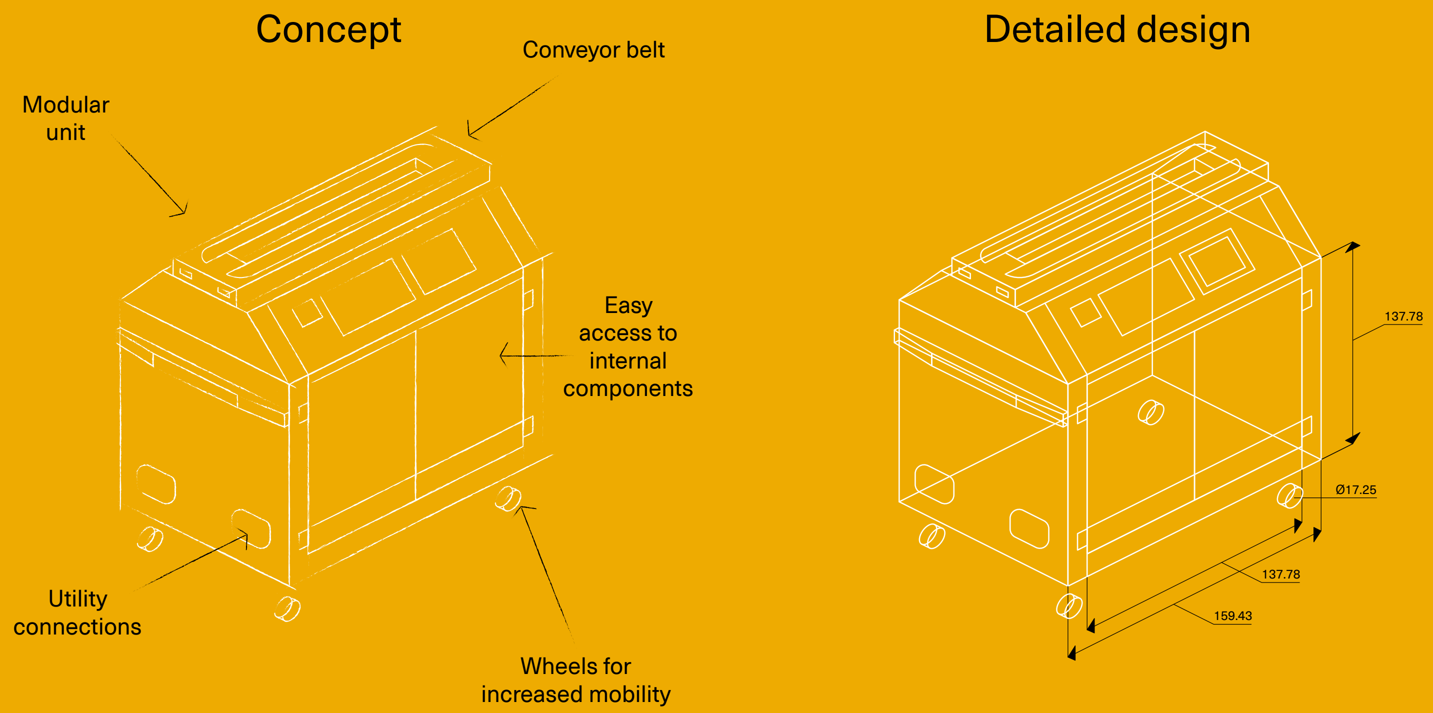


Figure 8.2. *From concept to detailed design.*

AAU SmartLab: A fully reconfigurable production system

At Aalborg University, there is a fully reconfigurable system known as the AAU SmartLab. The system is designed to demonstrate the assembly of a simple electronic product: a "dummy" mobile phone. The system is composed of standardized modules from Festo, each of which includes conveyor belts as well as control, network, electrical, and pneumatic connections to support different production equipment. The design of the AAU SmartLab allows the movement and reordering of the modules, as well as the ability to adapt the system's function by changing the production equipment mounted on the modules. This system meets the characteristics outlined for reconfigurable production systems in Chapter 2. The AAU SmartLab consists of both dedicated and flexible equipment. An example of dedicated equipment is the pallet system, which is specific for the size of the assembled products. In contrast, the robot cell is flexible within the existing product family.

>> *Read more about this REKON example on page 71.*

Activity 3.2: Evaluate the design against economic and technical requirements

When a detailed design has been made, it needs to be evaluated against the overall reconfigurability requirements established during the conceptual design phase, as well as specific economic and technical requirements. Examples of requirements could be to ensure that the system has capability to produce all variants of a product family, to ensure that the design cost is below a certain amount, or to keep the time needed for reconfigurations within a time limit.

The technical evaluation can be done using simulation tools and models, which allow the user to test different configurations and the ability to handle expected changes in demand. Besides the technical evaluation, a detailed economic evaluation is also needed. When making an economic evaluation of a reconfigurable production system, it is important to be aware of the fundamental differences between reconfigurable production systems and dedicated production systems. Using a traditional evaluation model for a reconfigurable production system will often provide a misleading picture of the economic profitability of this solution, as the system is designed to be adaptable to future product changes, ready for modules and interfaces that are not yet in use or can be reused across future systems and factories. Special investment models have been developed to consider the ability of a reconfigurable production system to be reused over time and for different product variants, as detailed in Chapter 5.

For this activity, it is advisable to use the REKON detailed model for economic evaluation of reconfigurable designs.

Detailed model for economic evaluation of reconfigurable designs

The tool for evaluating the economic feasibility of a reconfigurable production system is a detailed economic model that analyzes different modular and reconfigurable designs. It is designed to perform quantitative economic evaluations and requires input of information such as the system architecture, configurations, and production functionality. Additionally, it requires modeling of case- and industry-specific conditions and potentials in the production environment. The model uses rolling scenario optimization to handle complexity and uncertainty.

>> *Read more about this REKON tool on page 73.*

The outcome of evaluating the detailed design may lead to revisions of the design to better align it with the established requirements. Thus, step 3 may involve multiple iterations between activities 3.1 and 3.2 before a satisfactory design is reached.

Activity 3.3: Document design of final system

One of the fundamental principles of a reconfigurable production system is the ability to reuse equipment and processes. Therefore, it is essential to document the design in a way that allows future systems to benefit from reusing existing equipment designs as much as possible. Documenting the design enables future systems to be designed and developed based on a "plug-and-play" principle, rather than starting from scratch.

While traditional production equipment is typically documented with technical drawings and associated data sheets, documenting a reconfigurable production system also requires information about module functions, interfaces used, standards followed, and design limitations for interfaces. A library of modules can provide inspiration for this activity.

Library of modules

An effective way to gather knowledge about modules is to create a library of modules or designs. The library should include relevant master data for all modules, such as interfaces, module variants, platforms, and other essential information that can help future production development projects. The information can be collected in databases and IT systems, as well as in physical catalogs or booklets that can be easily accessed by designers and developers for inspiration and guidance.

>> *Read more about this REKON tool on page 74.*

Case:

Grundfos A/S utilizes ERP data to design the reconfigurable production system of the future

Grundfos A/S (Grundfos) is a global leader in the development and production of pumps for water and other liquids. With production facilities located all around the world, they have a vast number of production lines. The company offers a large and complex product portfolio, and therefore experiences challenges such as varying demand over time, and continuous introduction and phasing out of product generations and variants. These challenges ultimately create varying utilization of lines and equipment over time.

Despite the wide range of pump types and variants, such as small circulation pumps, submersible pumps, and multi-stage centrifugal pumps, there are many common features in the architecture of pumps. This leads to significant overlap and commonalities in the equipment used in production.

In other words, Grundfos has great potential for reusing and sharing equipment across products, production lines, and factories. For example, as the utilization of a specific line or equipment decreases due to falling demand for a specific product, it will be relevant to assess whether the line or some equipment can be reused for another product. This is the reason why the principles of modular and reconfigurable production have become crucial for the company. However, one of the big challenges for Grundfos is that knowledge about possible reuse is limited to individuals or written documents, making it difficult to search for and identify equipment in a specific factory that can take over specific production tasks.

Therefore, Grundfos joined the REKON project and focused on step 3 of the REKON method. The company developed an approach using ERP data to identify the capabilities of specific production lines and equipment in relation to product characteristics. This approach will be able to support Grundfos in creating an overview of existing equipment in terms of their product capabilities and will aid in searching for equipment to be used or reused for new production tasks, to increase capacity, or to move production. The approach has great potential in Grundfos, but requires further development, verification, resources, and data before its complete implementation.

Chapter 9

Step 4: Implementation and utilization of reconfigurability

Step 4 of the REKON method involves the implementation and utilization of reconfigurability in production. After the detailed design, installation and commissioning take place in this step, followed by the system going into operation. However, it can be difficult to separate operation, reconfigurations, and potential new designs for a reconfigurable production system, as the system's capabilities are continuously evaluated in relation to new requirements for functionality and capacity, and reconfigurations are made as needed. Therefore, step 4 is important for several reasons:

- New challenges and opportunities may arise during the lifetime of the production system due to product or technology development, which must be handled quickly to maintain competitive advantage.

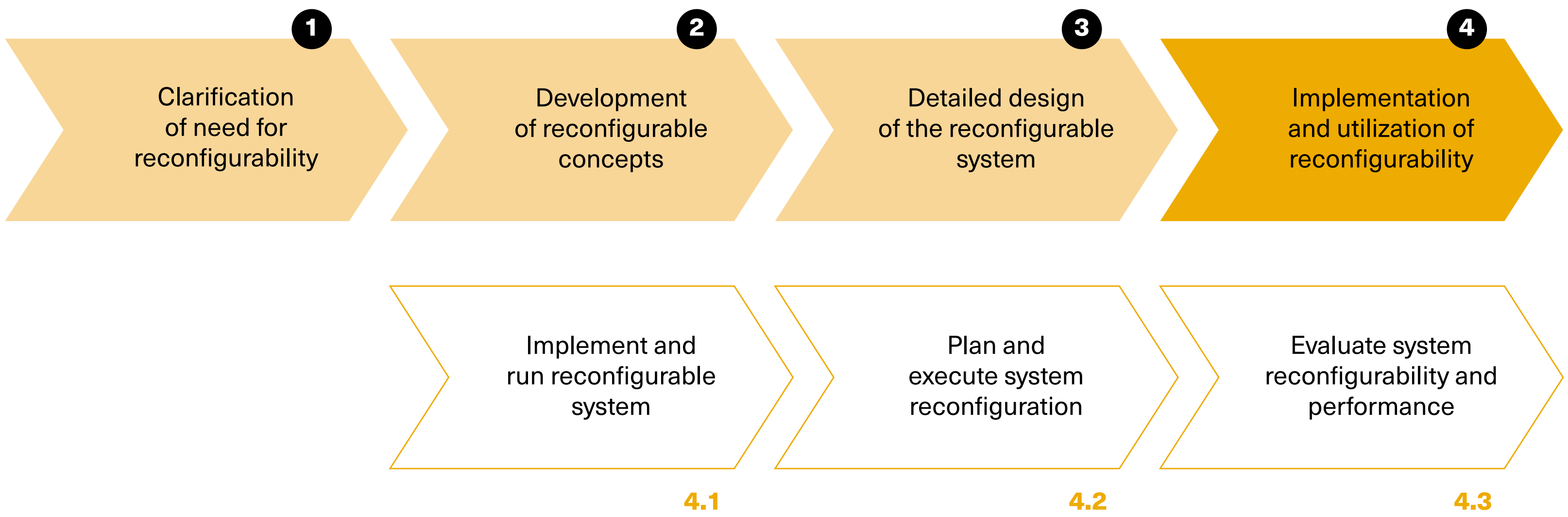


Figure 9.1. *Activities in step 4 of the REKON method.*

- A reconfigurable production system requires fast decision-making and capacity planning to operate effectively. In other words, if reconfigurations are not rapidly and efficiently implemented, the benefit of the reconfiguration is lost.

- Continuous monitoring of production performance and reconfigurability is necessary to identify new needs for increased reconfigurability and to ensure that requirements for reconfigurability are always met.

The three activities in step 4, illustrated in Figure 9.1, are designed to support these objectives. In the figure, the activities are illustrated as having a sequential and linear relationship. However, it is important to remember that the reconfigurable production system is constantly evolving, and there may be iterations between activities in step 4. For example, in activity 4.3 a need for reconfiguration may be identified, leading to iterations of activity 4.1 or 4.2. Additionally, if the system requires extensive changes, such as the development and introduction of new modules, iterations of earlier steps of the REKON method will be necessary.

Activity 4.1: Implement and run the reconfigurable system

With this activity, the reconfigurable production system is implemented. As a result, the production system will be in operation. Company-specific procedures for running, testing, and ramping up the new production system and equipment is often used in this step. It is important to note that the reconfigurable production system will be continuously changed in the short-, mid-, or long term in the form of alternative configurations. New configurations can include:

- Replacement of modules or components
- Changes in the layout of a line
- Introduction of new modules
- Increases and changes in automation

To ensure proper implementation and commissioning, it is essential to consider not only the first configuration or version of the production system to go into operation, future configurations also need to be planned. This should be done by defining clear guidelines and instructions that ensure that reconfiguration tasks are correctly implemented. These guidelines and instructions depend on the type of requirement and the company's previous experience with the specific reconfiguration. Requirements (short-, mid-, and long term) driven by variant, volume, and product changes lead to progressively more extensive reconfigurations. For example, a reconfiguration due to variant changes (short-term requirement) will often be less extensive than a reconfiguration caused by product changes (long-term requirement). Previous experience also supports the company in implementing reconfigurations, whereas in other cases the company may need to implement a reconfiguration that has never been performed before. Based on requirements and experience, six different situations can be described, as shown in Figure 9.2. The figure illustrates different types of reconfigurations of a production system, each requiring different procedures for implementation and commissioning.

The REKON tool for classification of reconfigurations and their commissioning is meant to inspire activity 4.1. Continuously updating the guidelines in each of the six identified situations will also support formalizing experiences over time reducing the time required for future reconfigurations.

Tool for classification of reconfigurations and their commissioning

This tool is used to classify different types of reconfigurations of a production system. It is based on whether the company has previous experience with the specific configuration and the type of requirements that need to be met (short-, mid-, or long term). For each type, supporting principles for hardware, software, and the virtual aspects of the system can be used.

>> *Read more about this REKON tool on page 75.*

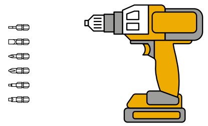
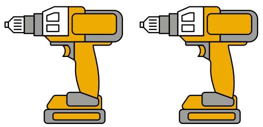
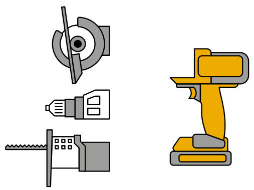
Need for reconfigurability in the production system		Previous experience with the needed change	
	**Short-term requirements**	Reconfiguration for variant changes done before	Reconfiguration for variant changes not done before
	**Mid-term requirements**	Reconfiguration for volume changes done before	Reconfiguration for volume changes not done before
	**Long-term requirements**	Reconfiguration for product changes done before	Reconfiguration for product changes not done before

Figure 9.2. *Different types of reconfigurations of a production system, requiring different guidelines for implementation and commissioning.*

Activity 4.2: Plan and execute system reconfiguration

After activity 4.1, the production system is in operation in one configuration or another. However, changes may still be needed during operation that do not require a significant implementation and ramp-up as in activity 4.1. These changes could include adjustments to processes, tools, resource allocations, or number of shifts, which are typically short-term in nature. In this case, the system's built-in flexibility is often used, or a few modules are replaced, which constitutes a minor reconfiguration of the system. For this type of frequent change, the REKON tool for predicting reconfigurations can be used. With this tool, it is possible to dynamically allocate resources such as operators or reconfigurable machines for daily tasks.

Tool for predicting reconfigurations

This tool can be used to generate a data-driven plan for configuring and reconfiguring the system. Despite the variability and customization of products, this tool can assist in predicting assembly times for each product variant and determining the required number of working hours, enabling the creation of an optimal production plan – for example, deciding on which specific day to run a particular configuration and when to switch to a different one.

>> *Read more about this REKON tool on page 76.*

Activity 4.3: Evaluate system reconfigurability and performance

This third and final activity in step 4 focuses on monitoring the current level of reconfigurability of the production system, as well as monitoring and evaluating ongoing system performance. This activity takes place not only immediately after a reconfiguration, but also throughout the entire lifetime of the system. With this activity, the company can continuously spot areas where it would be beneficial to increase the level of reconfigurability.

As the company faces new requirements for production and change drivers (also mentioned in Chapter 6), it may be necessary to iterate some of the steps of the REKON method after completing step 4, depending on the need for additional reconfigurability in production. This could for example be at a point after implementing a reconfigurable machine in production, where the product or market requirements have changed so much that the company will have to develop a new module for the machine. This will require the company to iterate step 3 for the detailed design of the new module. In another example, the same company may need reconfigurability at a different production stage, which would require an iteration of either step 1 – if the need for reconfigurability needs to be clarified – or step 2 if reconfigurable concepts can already be developed.

Simulation can be used as a tool in activity 4.3. By using simulation models, it is possible to test and verify changes in the reconfigurable production system, such as identifying bottlenecks, throughput times, utilization, etc. This allows us to investigate and test whether the current system, which is in operation, can produce new variants or whether design changes are necessary.

Simulation, particularly discrete event simulation, is a valuable tool not only in this activity, but also in the other activities in this step, as well as in other steps of the development of reconfigurable production systems, as detailed in Chapter 5.

Simulation of the reconfigurable production system

Discrete event simulation is a useful tool in many aspects of production development, particularly in the development and operation of reconfigurable production systems. It can be used to analyze and evaluate current production systems, calculate throughput times, assess waiting time, identify bottlenecks, etc. Simulation models can also be used to investigate potential system reconfigurations before implementation. There are various types of simulation software and methods for building models - therefore, case-specific decisions must be made.

>> *Read more about this REKON tool on page 77.*

Case:

Data-driven reconfiguration of assembly processes reduces throughput time by 45% at Elvstrøm Sails A/S

Elvstrøm Sails A/S (Elvstrøm Sails) is a Danish manufacturer in the sports equipment industry, and one of the two market-leading companies in the production of tailor-made sails for cruising and racing. The company offers a wide range of products, in different shapes, materials, and sizes - from a few square meters to over a thousand square meters.

Delivery time is a crucial competitive parameter for Elvstrøm Sails. To maintain its leading market position, the company always aims to reduce production lead times and, ultimately, the delivery time to customers, especially during periods of high demand and seasonal fluctuation.

The assembly of the sails is mainly manual and involves specialized processes that vary depending on the product and customer requirements. For example, specialized processes use very different tools and materials, leading to significant variations in assembly time.

Elvstrøm Sails aimed to improve the utilization of the company's existing changeability. In principle, manual production is extremely changeable by nature, as many different variants can be made, but each variant may require more or less time. Through an initial screening of the company's requirements and the existing level of reconfigurability in production, it was determined that improving changeability did not require the design of new equipment, but rather optimizing the utilization of the already existing flexibility and reconfigurability inherent in their setup. Therefore, the company focused on step 4 of the REKON method, specifically on activity 4.2.

To plan and execute system reconfigurations of the assembly processes, Elvstrøm Sails, in collaboration with researchers from Aalborg University, developed a tool for predicting reconfigurations. The tool predicts assembly times for each product variant and calculates the number of man-hours required each day at each assembly station. This information was used for daily planning of the assembly stages, allowing for better matching of employees to the day's workload.

By using this REKON tool, Elvstrøm Sails can now better distribute and balance assembly work among operators, reducing waiting times at all assembly stages and ultimately reducing the overall lead time by 45%, providing a significant competitive advantage.

Chapter 10

From the REKON method to reality

In this book, the 4 steps and 15 activities of the REKON method are described. Additionally, 13 specific tools and 2 examples are presented to assist in executing the various activities in a real development project. The REKON method begins with mapping of the company's specific change drivers within a specific product group or area of production and ends with a fully developed design, where reconfigurability can be utilized throughout the system's life cycle. Figure 10.1 provides a simplified overview of the entire REKON method and highlights key activities.

One of the key messages in this book is that reconfigurability and modularization of production can be highly beneficial for all types of production that face demands for increased changeability. The industrial cases presented in this book show that reconfigurability can be advantageous in a variety of industries, ranging from the production of wind turbines, sails, metering solutions, pumps, trucks, and even lettuce and mattresses. While the specific objectives and technical solutions may vary among these companies, they all share a desire for increased reuse, modularization, and reconfigurability.

The industrial cases in this book also highlight how different activities and tools of the REKON method have been applied. Vestas Wind Systems A/S and Ljusgårda AB have focused on economic and technical evaluation, while Kamstrup A/S and Grundfos A/S have mapped and documented products and production to create a foundation for increased reuse across systems and factories. Volvo Group Trucks Operations has implemented several steps and activities in the REKON method, while Dan-Foam ApS has used the screening of requirements for reconfigurability as input for a development project. Lastly, Elvstrøm Sails A/S has showed how data can be used to predict configurations of an already highly changeable assembly system.

The benefits of establishing modular, platform-based, and reconfigurable production are numerous and encompass both operational and strategic advantages. An example of a Danish company that has successfully developed, implemented, and utilized a reconfigurable production setup is Hydrema A/S.

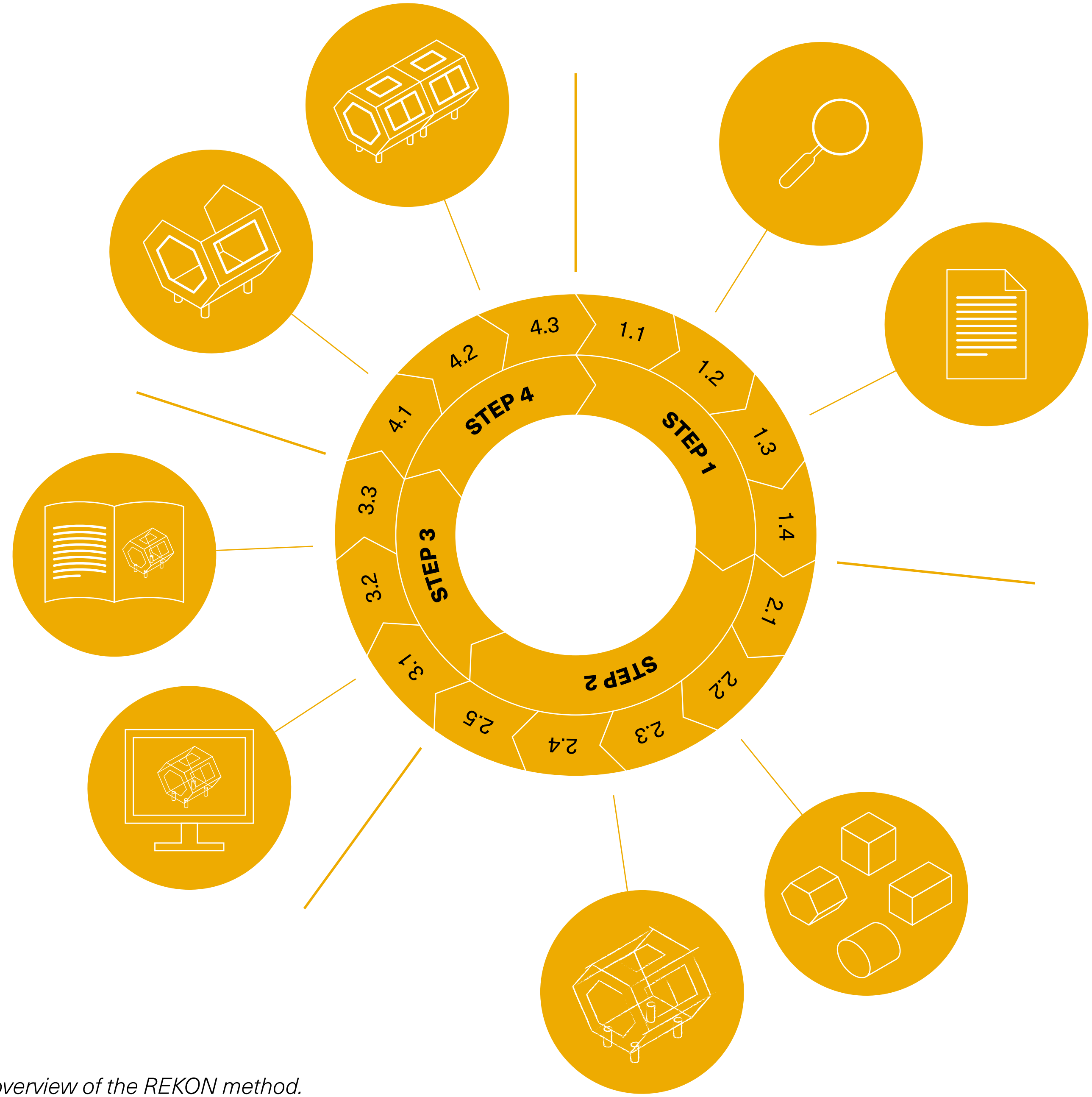


Figure 10.1. *Simplified overview of the REKON method.*

Case:

Reconfigurable welding fixtures provide a significant reduction in the number of machines needed and reduce changeover times by 80% at Hydrema A/S

South of Aalborg, the family-owned company Hydrema A/S (Hydrema) has been producing innovative construction machinery since the late 1950s. As the company has grown in both size and product portfolio, it has resulted in the use of a large number of dedicated welding fixtures. The production of construction machinery involves the welding of several larger components such as digging arms, chassis, and buckets. An example of one of these welding fixtures is shown in Figure 10.2.

These fixtures are traditionally only used for specific product variants, and the process of switching between them can be time-consuming and logistically challenging. In addition to the logistical challenges of frequently transporting these fixtures, their large size poses a significant challenge in terms of the space they occupy.

Given this situation, Hydrema recognized the potential in investigating the development of changeable and reconfigurable welding fixtures to reduce the challenges associated with using dedicated fixtures. The company was interested in developing fixtures that can be used for multiple product variants, reducing the need for extensive changes.

A research project with Aalborg University resulted in the development of a new type of modular and reconfigurable welding fixture, which enables reuse of the same equipment for an entire product family. The development process followed the same steps as the REKON method, including grouping components into families, identifying requirements for reconfigurability, identifying functions and module candidates, designing modules and interfaces, and assessing the potential of the new fixture. As a result, a new welding fixture was developed that was modular and easily reconfigured, as illustrated in Figure 10.3.

The introduction of this new welding fixture has helped Hydrema to enhance efficiency and significantly reduce changeovers, while also significantly reducing the number of large welding fixtures required.

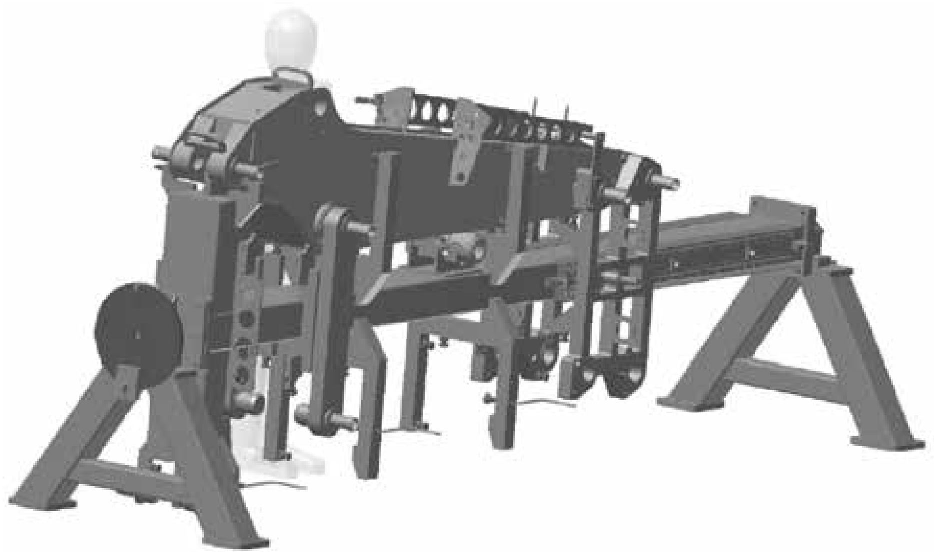


Figure 10.2. Illustration of one of the many dedicated welding fixtures.

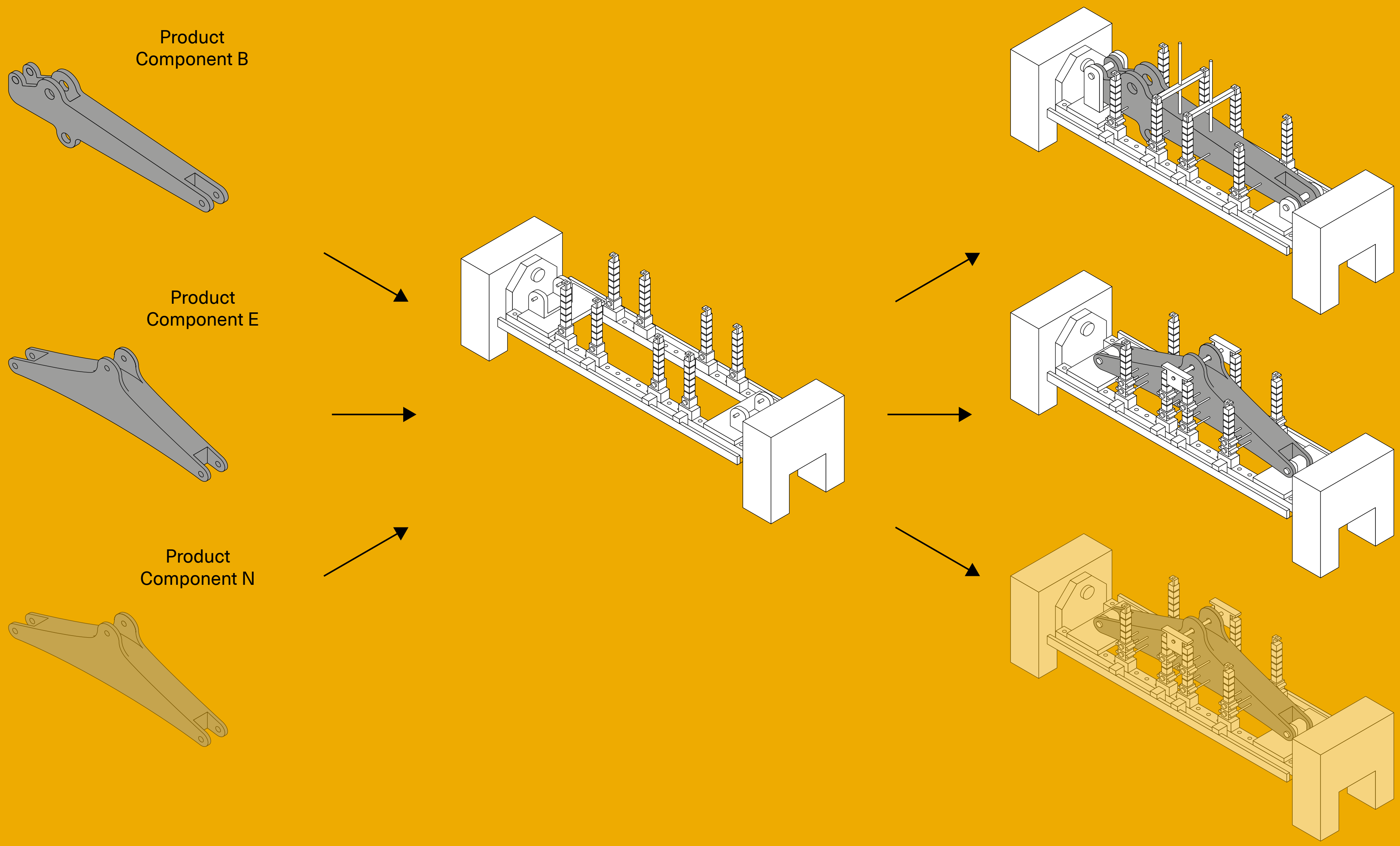


Figure 10.3. *Illustration of modular and reconfigurable welding fixtures.*

1.1 - Screening tool for assessing the need for reconfigurability

How it works

The tool consists of a series of Excel sheets for the identification of the need for reconfigurability in production through questions in three general categories: product, production and technology development. The tool requires a focus on selected product families and provides an effective overview of how these are affected by changes in both product design and production design. In addition, the tool supports the assessment of the company's ability to fulfill future product requirements from a production perspective. The questionnaire should be used as a starting point for discussion about current and future requirements for changes in production, focusing on one or more product families.

Additional material available online:
https://doi.org/10.5278/384b6055-89ee-4d0f-a4f1-7d74b15a7b60

Recommended reading

Napoleone, A., Andersen, A.-L., Brunoe, T. D., Nielsen, K. 2021. An Industry-Applicable Screening Tool for the Clarification of Changeability Requirements. In: IFIP Advances in Information and Communication Technology, 631: 471-478.

Andersen, A.-L., ElMaraghy, H., ElMaraghy, W., Brunoe, T. D., Nielsen, K. 2018. A participatory systems design methodology for changeable manufacturing systems. International Journal of Production Research, 56(8): 2769–2787.

Prerequisites

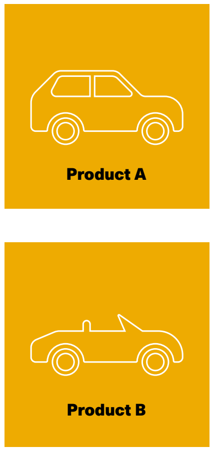
- Knowledge of product families, changes in product characteristics, and market evolution
- Knowledge of existing production systems

Employees

- Sales/marketing expert
- Strategy/investment expert
- Production manager
- Product expert
- Production developer

How to use it

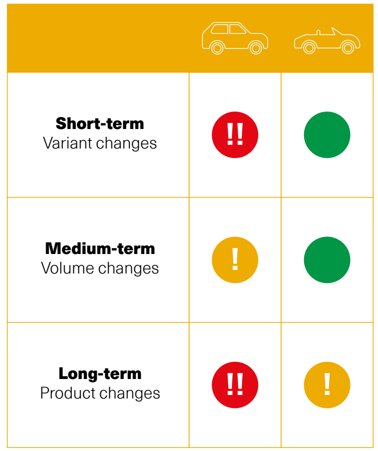
Select product(s)



Answer screening questions

Product		
Variety	X	X
Customization		X
Process requirements	X	
Product introduction	X	X
Product life circle		X
Production		
Production volume		X
Product mix	X	
Fluctuations in the production volume		
Teknology		
Process changes	X	X
Material changes		X

Need for reconfigurability



Expected results

- The short-, medium- and long-term need for reconfigurability in production is quantified and provide input to the identification of requirements for production system development.
- An analysis of current and future production requirements based on various "drivers" of changes.

1.2 - Screening tool for assessing reconfigurability of production

How it works

The tool consists of a series of Excel sheets with questions on characteristics of reconfigurability. The screening process starts by determining the desired level of reconfigurability through introductory questions, as well as identifying the production area to screen. Further questions related to reconfigurability are then answered to evaluate the reconfigurability of the production. This evaluation takes place by answering questions about each step of the production process. The answers are used to calculate a score, which is displayed along with a graphical summary indicating the level of reconfigurability.

Additional material available online:
https://doi.org/10.5278/384b6055-89ee-4d0f-a4f1-7d74b15a7b60

Recommended reading

Boldt, S., Rösiö, C., Bergström, A., Jödicke, L. 2021. Assessment of Reconfigurability Level within Existing Manufacturing Systems. In: Procedia CIRP, 104: 1458-1463.

Boldt, S., & Rosio, C. 2020. Evaluation of reconfigurability in brownfield manufacturing development. Paper presented at the Advances in Transdisciplinary Engineering, 13: 513-524.

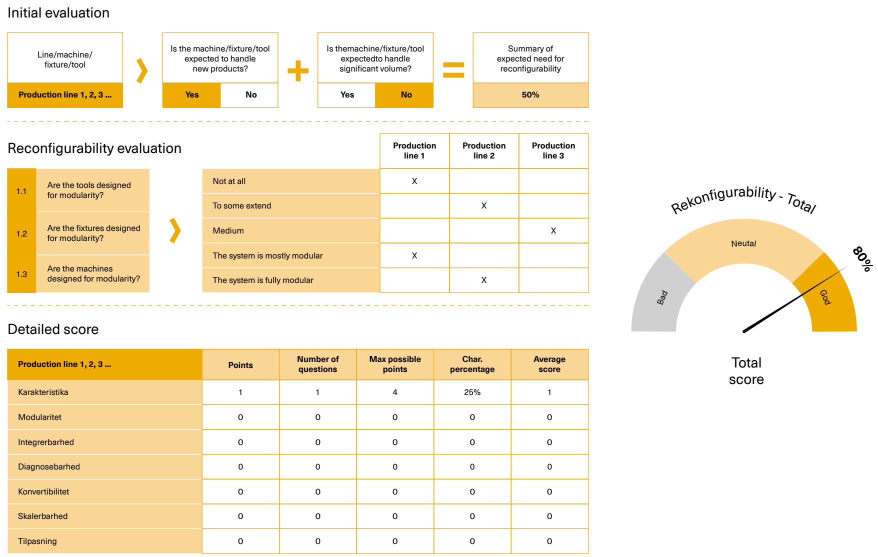
Prerequisites

- Knowledge of the production system, including equipment and interfaces.

Employeese

- Production developer
- Production engineergs
- Experts from specific areas in production

How to use it



Expected results

- An overview of the existing level of reconfigurability is shown and differentiated for the various reconfigurability characteristics. This can be used to guide the next phase of the development activities.
- The final score of the level of reconfigurability can be compared to the goal, which can guide further development.
- The tool can be used continuously to evaluate whether the desired level of reconfigurability is achieved.

1.3 - Business case tool

How it works

The tool is based on a simple method to calculate and simulate the total cost over the entire lifetime of the system, easily done in Excel. It calculates and discounts the operational and capital costs to present value. This is done for all possible demand scenarios, thus requiring Monte Carlo simulation. The types of necessary inputs are:

1 Characteristics (overall) of the concepts to evaluate, such as initial investment, investment for new products, area requirements, maintenance costs, conversion time, capacity expansion options, conversion downtime, etc.

2 Market need, including introduced products, expected volume reduction, and uncertainty (best case, worst case, most likely case) that must be addressed with possible scenarios.

3 Evaluation parameters, such as time horizon, discount rate, evaluated periods, etc.

Prerequisites

- Knowledge of the overall parameters for one or more alternative production setups
- Knowledge of possible scenarios for products and variants for a number of years in the future

Employees

- Production developer
- Project manager
- Manager

How to use it

1. Specify general characteristics of systems to be evaluated (input 1)
2. Specify possible scenarios for products and introductions in the future (input 2) and determine the overall parameters for the evaluation (input 3)
3. Set up deterministic model that calculates the discounted total cost for each system
4. Make a Monte Carlo simulation based on uncertainties and scenarios for product and introductions. Calculate total cost for each system in each scenario (e.g. 1000 times)
5. Aggregate the results for each system and evaluate each probability distribution.

Expected results

- Compare total costs for different overall types of production systems, such as a dedicated system versus a modular or reconfigurable one.
- Compare a more reconfigurable option to an existing system.
- Assess and evaluate overall economic aspects and potentials of reconfigurability in a specific context.
- Evaluate which type of system is cost-effective and robust against future production uncertainties.
- A solid foundation for deciding whether it makes sense to proceed with developing a concept and detailed design for a reconfigurable production system.

Recommended reading

Andersen, A. L., Brunoe, T. D., Nielsen, K., & Bejlegaard, M. 2018. Evaluating the investment feasibility and industrial implementation of changeable and reconfigurable manufacturing concepts. In; Journal of Manufacturing Technology Management.

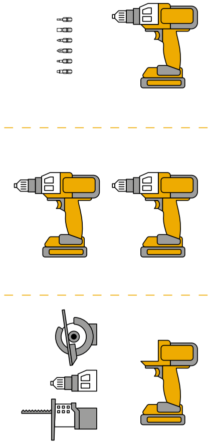
Brunoe, T. D., Napoleone, A., Andersen, A. L., & Nielsen, K. 2021. Impact of Different Financial Evaluation Parameters for Reconfigurable Manufacturing System Investments. In: IFIP International Conference on Advances in Production Management Systems (pp. 479-487). Springer.

1.4 - Example of list of reconfigurability requirements

How it works

This example shows how a list of requirements for the reconfigurable production system can be created. These requirements, which can be technical, economic or functional, serve as input for subsequent concept design definition, as well as for later evaluation of concept and detailed designs. One possible starting point is to distinguish between requirements for reconfigurability over different time frames, considering both structural and managerial changes in the system.

Example



Need for reconfigurability in the production system	Economic requirements: Output (product)	Economic requirements: Production	Technical requirements: Output (product)	Technical requirements: Production
Reconfiguration for variant changes **SHORT TERM REQUIREMENTS**	**Product:** • Cost of current variety needs to decrease by 50%	**Udstyr:** • Changeover cost	**Product:** • Range of variants	**Machine:** • Changeover time need to be reduced by 40% • Lot size dimensions need to decrease by 10%
Reconfiguration for volume changes **MID TERM REQUIREMENTS**	**Product:** • Cost of volume change	**Systems and sites:** • Training cost • Machine reconfiguration cost • Scalability cost • Space og facilities cost	**Product:** • Exp. volumes per variant	**Systems and sites:** • Utilization of tools • Utilization of machines • Utilizationof sites • Training time • Machine reconfiguration time
Reconfiguration for product changes **LONG TERM REQUIREMENTS**	**Product:** • Variety expansion cost needs to be reduced by 20% as new generation will be introduced	**Systems and sites:** • Design cost additional modules • Reconfiguration cost • No space available for new equipment	**Product:** • Time to market • Ilnspection time • Rework time	**Systems and sites:** • Reconfuguration time • Time to complete rump-up

Existing recongurability		
Green field	vs	Brown field

Expected results

- A list of reconfigurability requirements for the production system.
- Input for concept design.

2.1 - Product variant master (PVM)

How it works

A tool to visualize common and differentiated product functions within a product or a product family. Products are described using two different criteria: "part-of" and "kind-of". The so-called "part-of" criterion requires breaking down the product into its parts, thus providing an overview of the functions that constitute the product as a whole. In other words, "part-of" is the decomposition of a product in its components or functions. For each component or function, different "kind-of" options may also exist. The "kind-of" criterion requires listing the variants of a component or function. This tool can be extended to include additional perspectives:

- Customer perspective: describes product functions relevant to the customer
- Development perspective: describes how the product works
- Production perspective: describes the physical components of the product (bill of material)

Prerequisites

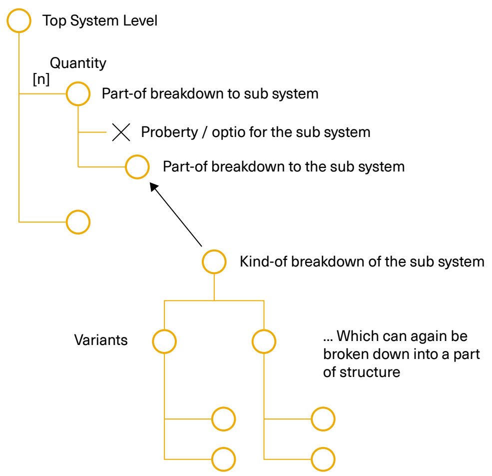
- Knowledge of product variety, including multi-level bill of materials

Employees

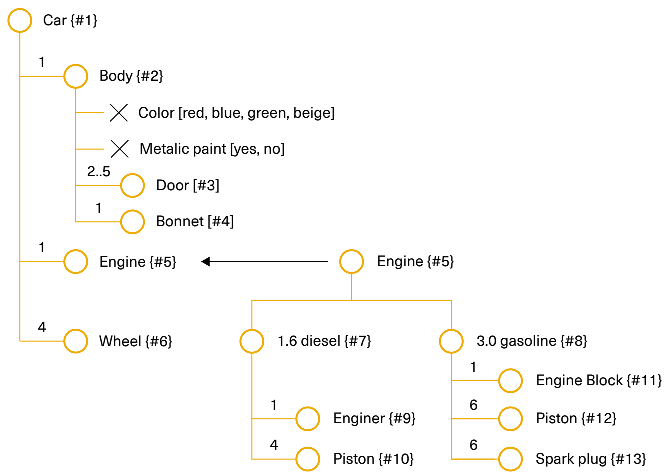
- Product developer
- Sales/ marketing representative

How to use it

Generic PVM



PVM eksempel



Expected results

- Mapping of product families using the product variant master makes it possible to analyze variation in the family in question and thus supports analysis of necessary variation in relation to the related production processes.

Recommended reading

Mortensen, N. H., Hvam, L., & Haug, A. 2010. Modelling product families for product configuration systems with product variant master. In ECAI 2010 Workshop on Intelligent Engineering Techniques for Knowledge Bases (IKBET) (Vol 1).

2.2 - Changeability mapping tool

How it works

A tool to assist both product and production developers in understanding the impact of product design decisions on the ability to produce new product variants using existing production processes. It is a four-step method that covers product analysis, process analysis and relationships between these two domains. Production developers can use the results to prioritize investments in new equipment or improvements to existing processes, based on the need for dedicated, flexible or reconfigurable equipment. The use of this tool is typically driven by unsatisfactory performance of existing processes or anticipated product changes. The method can also be beneficial outside the production department, as product developers can use the information to understand their design freedom based on existing production processes.

Additional material available online:
https://doi.org/10.5278/384b6055-89ee-4d0f-a4f1-7d74b15a7b60

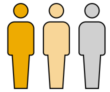
Recommended reading

Kjeldgaard, S., Andersen, R., Napoleone, A., Brunoe, T.D., Andersen, A.-L. 2023. Facilitating Manufacturing System Development: Mapping Changeability Capabilities in Two Industrial Cases. In: Lecture Notes in Networks and Systems, 546: 626-635.

Schou, C., Sørensen, D. G. H., Li, C., Brunø, T. D., & Madsen, O. 2021. Determining manufacturing system changes based on new product specifications. In: Journal of Global Operations and Strategic Sourcing, 14(4), 590-607.

Prerequisites

- Knowledge of product characteristics
- Knowledge of process capabilities
- Knowledge of relationships between product characteristics and processes

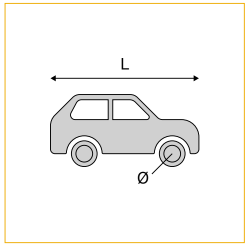


Employees

- Product developer
- Production developer

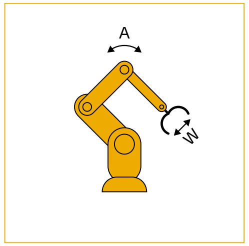
How to use it

Step 1



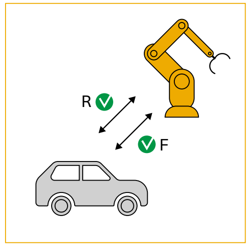
Identify product characteristics that are essential to determine whether the product can be produced using existing processe,s as well as characteristics that are expected to change in the future.

Step 2



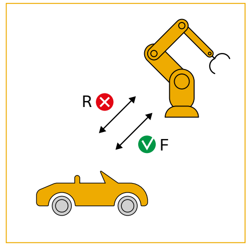
Identify relevant production processes for the selected product family. A list of processes and their capabilities is typically created.

Step 3



Map relationships between product characteristics and production processes, identifying the processes affected by changes between product variants or by the introduction of new variants. This can be represented in a two-dimensional table.

Step 4



Identify the impacts on the identified processes when switching between product variants or introducing new ones by comparing existing and required changeability.

Expected results

- Gain insight into the impact of product characteristics on specific production processes and their changeability.
- Understand the adequacy of production processes with existing and future product variants.
- Evaluate the need for increased changeability in specific production processes based on expected product changes.

2.3 - Catalogue of reconfigurable solutions

How it works

Several industrial companies offer reconfigurable production equipment. This catalogue is a small selection of various solutions for increased reconfigurability. The catalogue is not intended to be a complete collection, but serves as inspiration, showcasing different forms and industrial applications of reconfigurability across levels of production with varying time horizons. The examples range from local SMEs to large manufacturing companies, covering a diverse range of industries.

How to use it

	Physical		Logical	
	Equipment	**System**	**Software**	**Operator**
Short-term Variant changes	• Movable fixture supports • Robotic fixturing • Modular moulds	• "Plug-n-play" modules for variety in food production • Modular sorting machine for the agricultural sector	• Tool for predicting reconfigurations	• Multi-skilled operators
Medium-term Volume changes	• Mobile modular workstations • Scalable "2D-printer" • Modular processing plant in food production	• Space for capacity expansion • Modular processing plant in food production	• Simulation	• Exoskeleton to scale capacity in manual operations • Flexible shifts and multi-skilled operators
Long-term Product changes	• Mobile modular workstations • Reconfigurable machine tool • Modular processing plant in food production	• Modular assembly system • Reconfigurable final assembly	• Virtual reality to train operators • Smart robots • Simulation	• Training procedures • Multi-skilled operators

Additional material available online:
https://doi.org/10.5278/384b6055-89ee-4d0f-a4f1-7d74b15a7b60

2.4 - Modular function deployment for production (MFDP)

How it works

Modular function deployment is a recognized method for designing modular products, originally developed for this purpose. The method has been expanded and presented in this book to include the design of modular production systems.

MFDP comprises five sequential steps that cover all stages of production system design, from specifying system requirements to detailed design of production modules. An essential element of MFDP is the use of "module drivers" (see Table 1, page ~~XX~~) to guide designers in modularization decisions. The method is iterative and may require revisiting previous steps, which is why the method is often depicted as circular.

Prerequisites

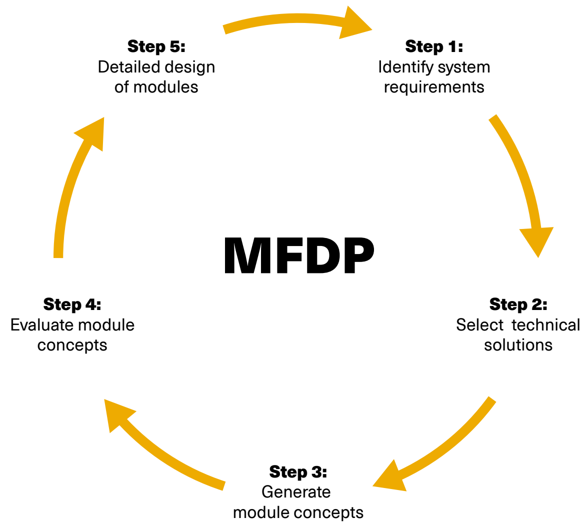
- Knowledge of product and production strategy
- Knowledge of relationships between product characteristics and processes

Employees

- Product developer
- Production developer

How to use it

1. Clarification of requirements in terms of production system functions based on product characteristics using a two-dimensional table inspired by the Quality Function Deployment method.
2. Evaluation of technical solutions for the identified system functions, and selection of the best option for each function.
3. Generation of module concepts and interfaces based on the company's product and production strategy, including groupings of module drivers and system functions.
4. Evaluation of the generated module concepts against modular design parameters and company goals. The evaluation enables the selection of the most suitable module concept.
5. Detailed design of the selected module.



Recommended reading

Brunoe, T.D., Bossen, J., Nielsen, K. 2015. Identification of Drivers for Modular Production. In: IFIP Advances in Information and Communication Technology, 459: 235-242

Börjesson, F. 2014. Modular Function Deployment Applied to a Cordless Handheld Vacuum. In: Advances in Product Family and Product Platform Design, 605-623.

Ericcson and Erixon. 1999. Controlling Design Variants: Modular Product Platforms. Society of Manufacturing Engineers.

Expected results

- Analysis of product requirements and production processes to understand impacts of product variety on production processes
- Functional analysis of production system requirements to increase freedom in design choices
- Consideration of product and production strategy in module generation to link modularity to business needs
- Development of one or more production modules

2.5 - Ranking hierarchy and matrix

How it works

The evaluation of design concepts can be challenging, as a wide set of important parameters such as technical benefits like scalability or convertibility, often are difficult to quantify. Moreover, different companies may value parameters differently. This Excel-based tool supports the company prioritizing parameters by conducting simple pairwise comparisons. The resulting ranked list provides production developers with a reference to evaluate the performance of each design concept based on the most relevant parameters. The tool is particularly useful in highlighting and quantifying qualitative parameters that may be extremely important when considering the introduction of modular and reconfigurable production systems.

Additional material available online:
https://doi.org/10.5278/384b6055-89ee-4d0f-a4f1-7d74b15a7b60

Recommended reading

Napoleone, A., Brunoe, T. D., Andersen, A.-L., Nielsen, K. 2021. A Tool for the Comparison of Concept Designs of Reconfigurable Manufacturing Systems, Procedia CIRP, 104: 1125-1130

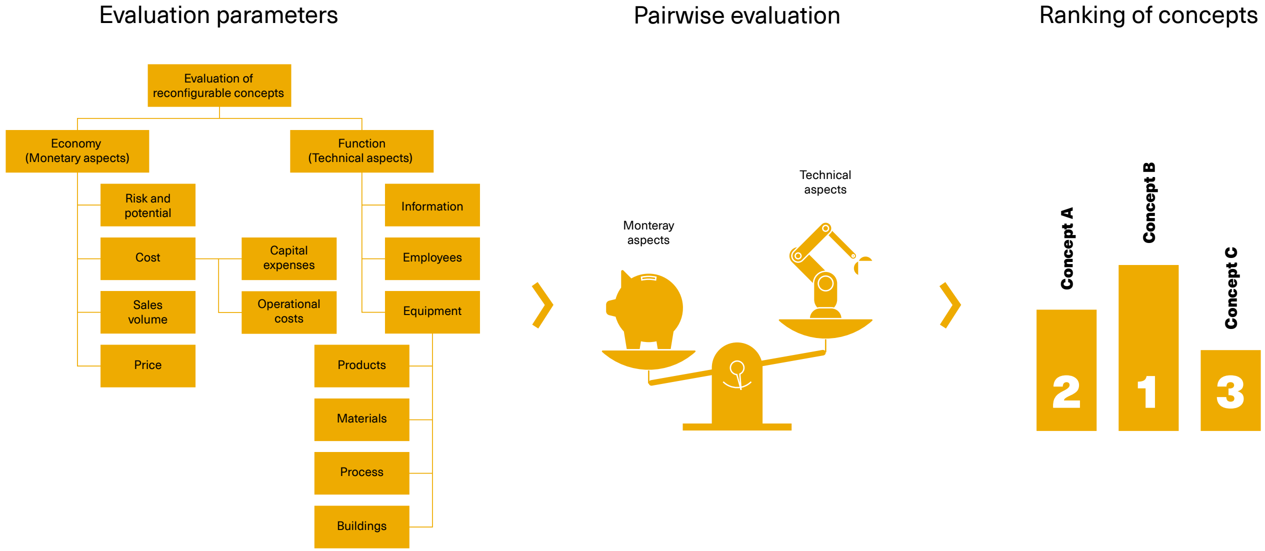
Prerequisites

- Knowledge of system characteristics (architecture, performance, constraints, etc.)
- Supply chain characteristics and constraints
- Product demand

Employees

- Production developer
- Production planner
- Supply chain manager

How to use it



Expected results

- A ranked list of design concepts, based on the specific needs of the company
- Quantification of technical parameters, such as scalability and convertibility
- Relatively quick and simple evaluation of design concepts.

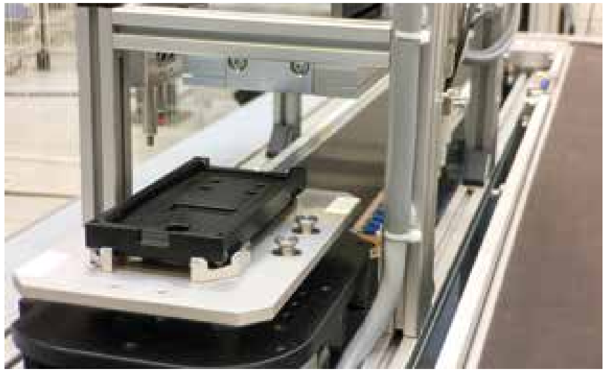
3.1 - AAU SmartLab: a fully reconfigurable production

How it works

Aalborg University's SmartLab is a fully reconfigurable production system. The system is designed to demonstrate the production of a simple electronic product: a "dummy" mobile phone. Most of the equipment has been developed by Festo for educational purposes. It consists of standard modules that can be configured and scaled to almost any configuration. The system's functionality and capacity of can be further customized by adding differentiating modules to the standard ones.

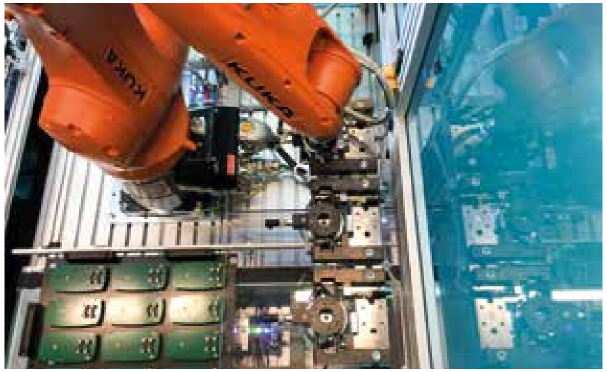
Standard modules

The standard modules – or platforms - are components that can be moved, rearranged, and even reconfigured by adding different process modules, such as automatic product inspection or drilling. These platforms can also be connected to other process modules, such as the robot cell.



Dedicated equipment

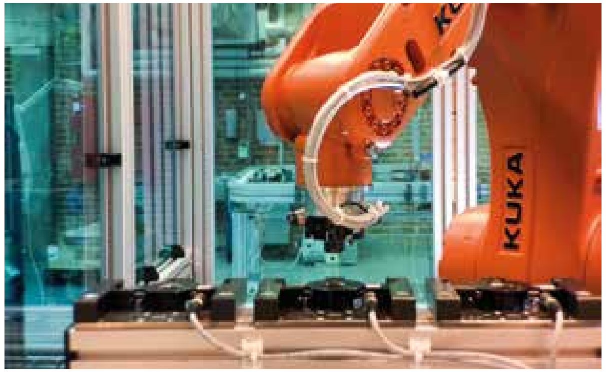
The tray holding the printed circuit board is standard for the product, and the feeding unit is therefore dedicated to feeding only one type of tray.



Flexible equipment

Although the robot cell is designed for a specific product, the robot is flexible to install a varying quantity of fuses on printed circuit boards.

3.1 - AAU SmartLab eksempel



Reconfigurable equipment

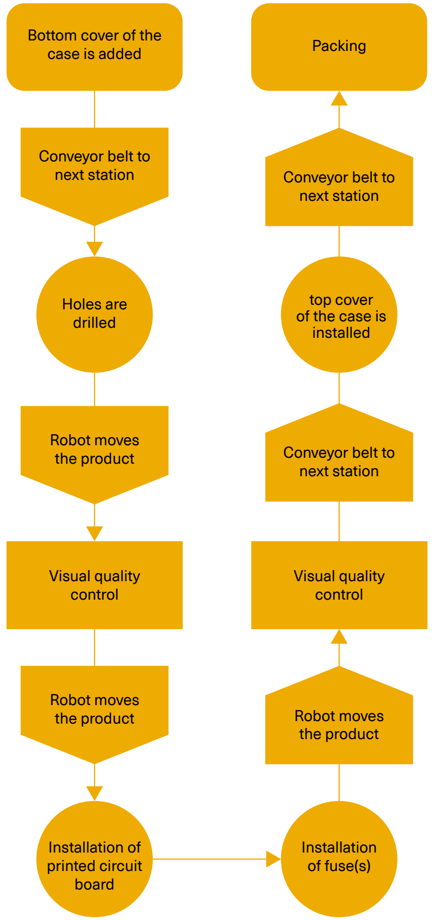
The robot performs different tasks like moving printed circuit boards and picking up fuses. To perform these different tasks, it requires different grippers. The robot is reconfigurable because it can convert its functionality by changing grippers.

Product

The product is a dummy mobile phone consisting of a lower and upper case, a printed circuit board, and one or two fuses. The parts are assembled and holes are drilled in the printed circuit board during the assembly.

System configuration

The system is modular and the shown configuration is one of many possibilities, other configurations are driven by desired changes in functionality or capacity for the production line.



This process flow outlines the processes involved and their sequence in assembling the electronic product.

3.2 - Detailed model for economic evaluation of reconfigurable designs

How it works

This tool supports creating a model for quantitative economic evaluation of designs, customized for a specific case, thus considering case- and industry-specific constraints and potentials. Multiple data are needed to setup the model, for example the input shown in the generic representation of the model. The evaluation of each design requires specification of aspects such as:

- Production functionality and architecture which determine the variety, standardization and reusability of modules across product variants.
- Reconfiguration time and ramp-up time between configurations, as well as procurement costs
- Resources and procedures in the planned production environment (employees, cycle times, space requirements, planning, etc.)
- Scenarios for different demand patterns based on forecasts and/or historical data

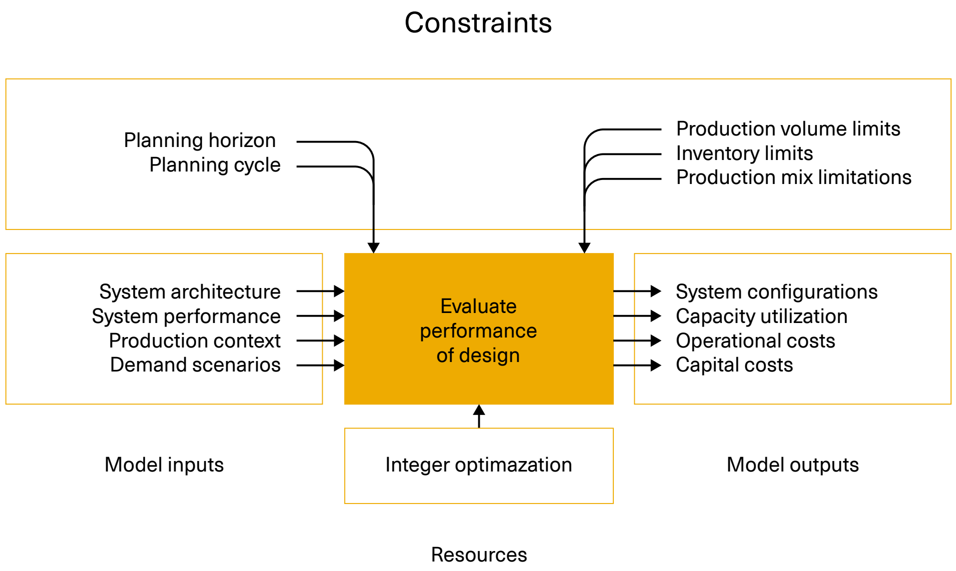
Prerequisites

- Knowledge of system characteristics (architecture, performance, constraints, etc.)
- Supply chain characteristics and constraints
- Product demand

Employees

- Production developer
- Production planner
- Supply chain manager
- Relevant stakeholders across the company

How to use it



Recommended reading

Kjeldgaard, S., Jorsal, A. L., Albrecht, V., Andersen, A-L., Brunoe, T. D., Nielsen, K. 2021. Towards a model for evaluating the investment of reconfigurable and platform-based manufacturing concepts considering footprint adaptability. In: Procedia CIRP 104, 553-558.

Expected results

- Generates key figures for capital and operational costs, as well as a number of operational parameters.
- The results can be used to calculate Delta and Net Present Value.

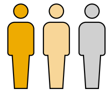
3.3 - Library of modules

How it works

When designing production systems and equipment with reuse in mind, documenting design decisions is crucial. This information is usually documented in various ways, but generally contains structured information about the modules. There are several reasons for documenting design decisions for modules in a production system. For example, having a record of the capabilities of production modules speeds up the system development process, It also supports clarifying which product variety can be accommodated using existing production modules.

Prerequisites

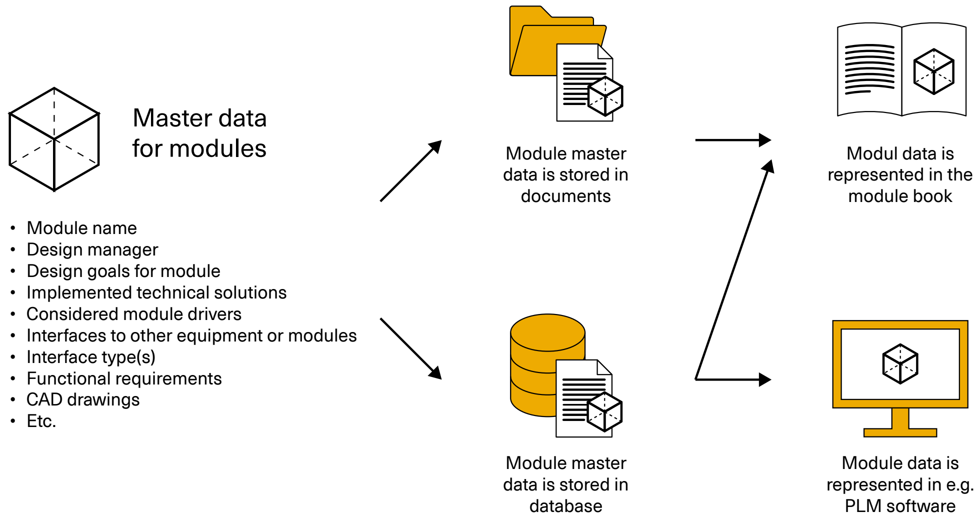
- Relevant design data for production modules
- Knowledge of production systems



Employees

- Production developer
- PLM expert
- PLM user

How to use it



Recommended reading

Ericcson and Erixon. 1999. Controlling Design Variants: Modular Product Platforms. Society of Manufacturing Engineers.

Expected results

- Well-documented master data that is easily accessible, speeds up and lowers the cost of designing new production systems
- Documented and established design knowledge of production modules reduces the cost and effort for designs, enabling reuse of designs and modules.

4.1 - Tool for classification of reconfigurations and their commissioning

How it works

This tool can be used to classify different types of production system reconfiguration. The classification is based on previous experience with the needed configuration and on the addressed need for change (short-, medium- or long-term). For each type, guidelines and instructions for hardware, software and virtual components of the system can be determined. It is advisable to start with this classification, and then supplement the different types of reconfiguration with company-specific guidelines.

Prerequisites

- Knowledge about previously implemented reconfigurations in production

Employees

- Production developer
- Production manager
- Operators involved in reconfigurations

How to use it

Need for reconfigurability in the production system		Previous experience with the needed change: **Has been done before**	Previous experience with the needed change: **Has not been done before**
Reconfiguration for variant changes	**Short term. req. Low complexity**	Replace tool. Execution calibration.	Varify virtual availability tool. Commission new tool. Execute software adaption.
Reconfiguration for volume changes	**Mid term. req. Mid complexity**	Add/remove standard module. Update software. Execute ramp-up procedure.	Add/remove modified module. Commission modified module. Execute software adaption.
Reconfiguration for product changes	**Long term. req. High complexity**	Exchange standard module. Update software. Execute ramp-up software.	Exchange modified module. Commission modified module. Upgrade software.

Recommended reading

Mortensen, S. T., Madsen, O. 2019. Operational Classification and Method for Reconfiguration & Recommissioning of Changeable Manufacturing Systems on System Level. Procedia Manufacturing, 104: 1125-1130.

Expected results

- An overview of the reconfigurations that have been previously implemented in production, as well as of those changeovers, extensions or conversions that have not been implemented yet.
- Possibility to expand this classification with guidelines for each type of reconfiguration to ensure that these are performed correctly and quickly.

4.2 - Tool for predicting reconfigurations

How it works

This tools predicts workloads and thus need for operators at the different manual workstation by analysing product and production data with machine learning. It considers product characteristics affecting the production time, and uses historical production data to estimate the time required for each task and balance the overall production time. The tool can also estimate process time for new product variants based on their characteristics.

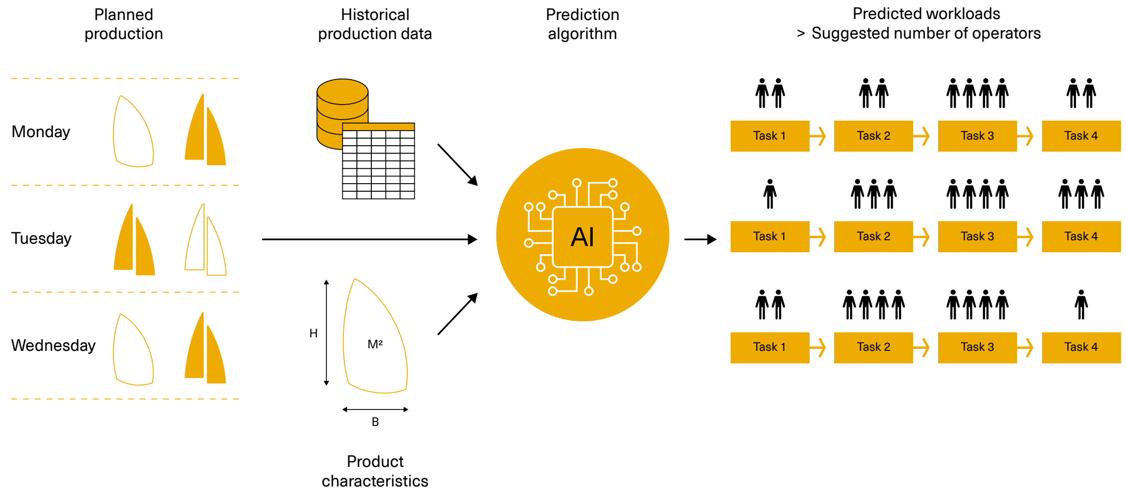
Prerequisites

- Knowledge of product characteristics
- Historical production data
- Production plan

Employees

- Product developer
- Production manager
- Production planner

How to use it



Expected results

- Reduction of waiting times caused by unbalanced allocation of operators thanks to the more accurate prediction of working times for variant-specific tasks, leading to reduced throughput time in production.
- The relationships between product characteristics and production times are better understood, these support more accurate estimate of process time for new product variants, thus leading to more accurate cost calculation for new product variants.

4.3 - Simulation of the reconfigurable production system

How it works

Developing a simulation model for a production system can be resource-intensive, but the benefits of a simulation model for reconfigurable systems make the investment worthwhile. With simulation models, virtual production modules and their functions can be modeled, and alternative configurations can be tested before implementation. In addition, it is possible to evaluate options for reusing existing modules in different configurations, thus reducing process development costs and reconfiguration times. Ultimately, this enables increasing confidence in the functionality and performance of new configurations among operators and management.

Additional material available online:
https://doi.org/10.5278/384b6055-89ee-4d0f-a4f1-7d74b15a7b60

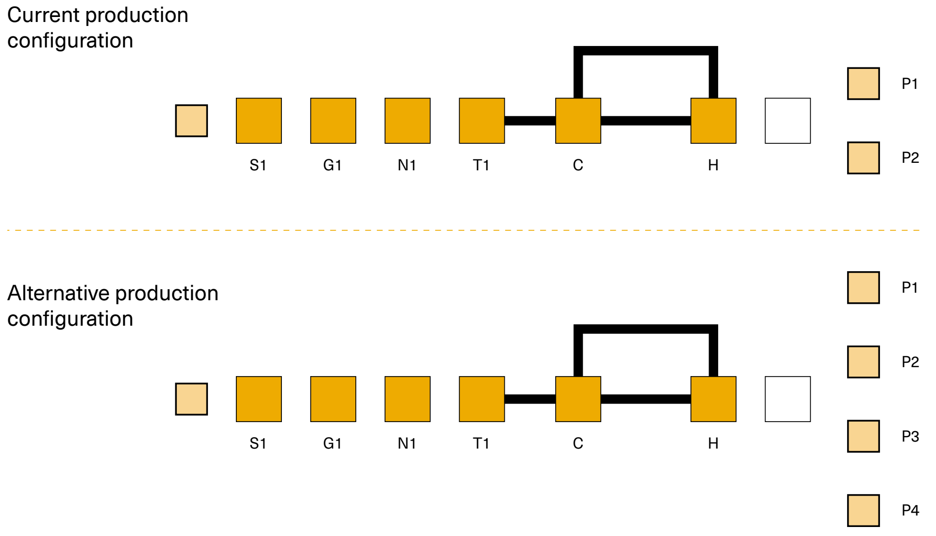
Prerequisites

- Knowledge of the production system's layout
- Knowledge of equipment, and process parameters such as functionality and performance

Employees

- Production developer
- Production manager
- Operators with experience with affected processes
- Simulation expert

How to use it



Expected results

- Simulation of different demand patterns and product mixes and their impact on different configurations.
- Insights on how different configuraitons of the system performs under varying conditions and scenarioes.

List of suggested readings

The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems
Koren, Y., 2010, John Wiley & Sons, Inc., 978-0-470-58377-7

Handbook Factory Planning and Design
Wiendahl, H.-P. Reichardt, J. and Nyhuis, P., 2015, Springer-Verlag Berlin Heidelberg, 978-3-662-46390-1

Production Development: Design and Operation of Production Systems
Bellgran, M. and Säfsten, K., 2010, Springer-Verlag London Limited, 978-1-84882-494-2

Changeable Manufacturing - Classification, Design and Operation
Wiendahl, H.-P. et al., 2007, CIRP Annals, Vol. 56, 2, Elsevier

Evolution and Future of Manufacturing Systems
ElMaraghy, H. et al., 2021, CIRP Annals, Vol. 70, 2, Elsevier

Product Variety Management
ElMaraghy, H. et al., 2013, CIRP Annals, Vol. 62, 2, Elsevier

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Paving the way for changeable and reconfigurable production

This book is for professionals working with the development of production systems. It provides guidance on how to design production systems capable of meeting uncertain market requirements in the future, whether these are fluctuations in demand volume, requirements for product variants, or introduction of completely new product families.

- An introduction to the fundamental principles of changeable, reconfigurable, modular, and platform-based production systems.
- A research-based method for developing reconfigurable production systems.
- Practical tools for analyzing existing capabilities, developing new concepts, and evaluating these.
- Examples from Danish and Swedish production companies of various sizes and industries.

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