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Impact of product modular design on agile manufacturing

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1. Introduction

1.1 Agile manufacturing features

Agility is defined as the ability to thrive and prosper in a competitive environment of continuous and unanticipated change, and to respond quickly to rapidly changing markets and customer demands [1]. A key element of agility is agile enterprise. Agile enterprises are totally integrated organizations, because information flows seamlessly among manufacturing, engineering, marketing, purchasing, finance, inventory, sales and research [2]. Agile manufacturing is the *economy of easy* with which a company can react to new opportunities. Becoming an agile, virtual company does not necessarily mean down-sizing. It is merely a concept to be used while designing products and manufacturing processes so that when markets change or when customers need change, agility in the process can come to the rescue, allowing reconfiguration of the setup with calculated penalty and change in product offerings. Agility is part of the measure of merit that needs to be considered in product realization [3].

The aim of this research is to consider how the product modular design can increase its offerings and also can allow the manufacturing process to reach *economy of easy* quickly reacting to markets change.

1.2. The means of product variety raise

There are various ways to manage and control product range complexity. It is important to acknowledge the importance of certain terms when analyzing and evaluating the efficiency and functionality of modularity. There are various concepts of design, each of them focusing on a certain critical process. When a product has been designed for modularity, it makes the product easier and more cost efficient to produce, or more valuable for the customer. Many aspects in design and utilization have been considered relating to modularity [4-8].

The concepts of design for manufacturing (DFM) and design for assembly (DFA) focus on reducing costs by making the products easier to produce. Usually these concepts concentrate on a company's internal interests.

Many manufacturers have the mission to buy their raw material at the right time, process them efficiently in the plant, and deliver the products to the customers when they need them. This requires good relationships with the vendors and Just-in-Time (JIT) logistics. With well-designed and carefully arranged logistics, companies can achieve cost savings and better customer satisfaction. This design for logistics (DFL) is something that only a few designers consider, but it is significant for a successful product.

1.3. Recognition of need to products customisation

The key to product customization is to postpone differentiating a product for a specific customer until the latest possible point in the supply network. Three organizational design principles form the basic building blocks of efficient mass-customisation:

- a product should be designed so that it consists of independent modules that can be assembled into different forms of the product easily and inexpensively;
- the manufacturing processes should consist of independent modules that can be moved or rearranged easily to support different distribution-network designs;
- the supply network – the positioning of inventory and the location, number, and structure of manufacturing and distribution facilities – should be designed to provide two capabilities: 1) to supply the basic products in a cost efficient manner, 2) flexibility to quickly delivery the finished customised goods [4-5].

2. Modular design

2.1. Modular types

To be able to analyse and measure the efficiency of existing modularity, it is important to understand the basic idea of design modularization and its effects on the product range complexity. Modularity is a product strategy for organizing complex products and processes efficiently by dividing them into independent units or modules that can be altered individually, but they still function as integrated wholes [9].

Visible design rules are decisions that affect the subsequent design decisions. Ideally, the visible design rules are established early in a design process and communicated broadly to those involved. The visible design rules fall into three categories:

The architecture, which specifies what modules, will be a part of the system and what their functions will be. *Interfaces* that describe in detail how the modules will interact, including how they will fit together, connect and communicate. *Creation* the standards, which test the conformity of a module to the design rules and measure the match of one module performance relative to another?

Modularity allows a part of the product to be made as standard modules with product distinctiveness achieved through combination or modification of the modules. Therefore, the modules that will be used in the custom product can be manufactured with mass production techniques. The modular approach can reduce the variety of components while offering a greater range of end products. It has also been argued that modularity can shorten the delivery times and provides economies of scope [10].

Contrary to the above mentioned use of modularization in mass production, when the products are unique and their costs are related to engineering hours, the advantages of modularization are most significantly used in design and engineering.

2.2. Customer involvement and modularity classification

Product customisation has two critical identifiers: customer involvement in the product life cycle and modularity. Bringing these concepts together, mass customisation can be defined as building products to customer specifications using modular components to achieve *economies of scale***.** A distinction can be made between product customization based on the point at which the customer becomes involved in the design process and the type of modularity employed by the producer. These two attributes are interrelated and taken together suggest product customisation archetypes. The biggest effectiveness of customer involvement in product and process design is in their early development stage (Fig. 1). Tardy customer involvement in product manufacturing stage has low efficiency. It is confirmed also by other researchers [11-13].

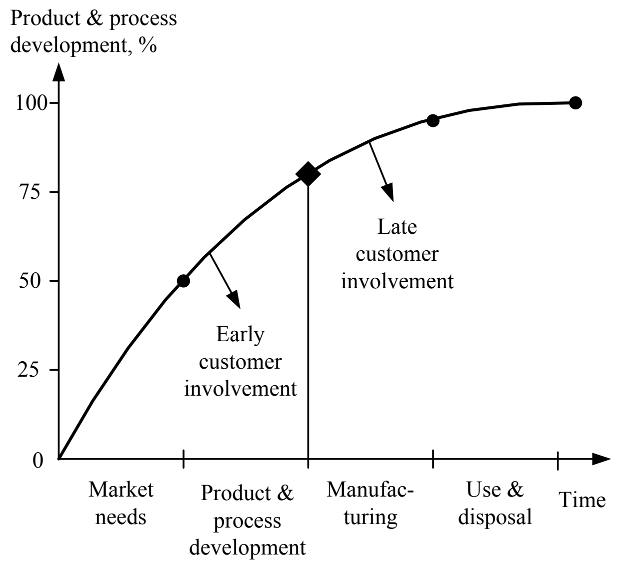


Fig. 1 Customer involvement in product and process life cycle stages

There are four types of modularity and points of customer's involvement into product customization: product design, fabrication, assembly and use. The executors of product and process modularity also are divided into four groups: fabricators, involvers, modularizers and assemblers [14].

Fabricators include both customer involvement and modularity during the product design and fabrication stages. The fabricators involve the customers early in the process when unique designs can be realized or major revisions made in the products. They closely resemble a pure customisation strategy, but employ modularity to gain commonality of components. Customers are involved in the design and fabrication stage of the product cycle, and component sharing and cut-to-fit modularity are used to provide the mass customized product.

Involvers incorporate customer involvement in product design and fabrication stages, and employ modularity during the assembly and use stages. With the involvers, the customers are involved early in the process, although no new modules are fabricated for a certain customer. Customisation is achieved by combining standard models to meet the specification of the customer. The involvers capture greater economies of scale than the fabricators, while maintaining a high level of customer involvement.

Modularizers involve the customer during assembly and delivery, but incorporate modularity in the design and fabrication stages. The modularizers develop a modular approach in the design and fabrication stages, although the customers do not specify their unique requirements until the assembly and use stages. The Modularizers use modularity earlier in the manufacturing process than when customisation occurs. The modularity may be considered component commonality (common features of components). In this type, the modularizers may not gain maximum customisation advantages from modularity.

Assemblers bring both customer involvement and modularity to the assembly and use stages. The assemblers provide mass customisation by using modular components to present a wide range of choices to the customer. Assemble-to-order manufacturers can be considered mass customizers if the customers specify products from a predetermined set of features. The assemblers resemble the operations of mass production more clearly than the other configurations of mass customers. The assemblers differ from mass producers in that the products have been designed so that the customer can be involved in specifying the product. Because the range of choices made available by the Assemblers is large relative to mass producers, customers perceive the product as customized.

3. Modularisation concept of project business product

3.1. Identification of the customer needs

Customer needs can be divided to homogeneous or heterogeneous needs. A major part of customers have homogeneous needs for the product, especially when the product is in the early stage of its life cycle, e.g. it represents new technology, or it is a product of process industry. The customers make their buying decisions on the basis of the product's price, delivery time, quality or auxiliaries. A single customer or a small group of customers may have special requirements for the product, and then we talk about heterogeneous customer needs [14].

When designing product policies, it must be considered whether to satisfy specific customer needs or not. The driving force of the product policy is to aim to close the deals with best possible profits or the existing technology. When deciding not to respond to some specific customer requirement, we must remember that the trend is towards global markets and the decision might exclude an entire market in the future. Sales people are the key personnel with their knowledge and information, when dropping off some customer requirements. On the other hand, they might have some burdens from past successful products. These requirements or products were successful at some point, but now the market trends have changed. When the product policy is made, the next step is to transform and construct the customer requirements into modules [14].

3.2. Modularization concept of a project business company

Companies which deliver unique products to their customers have adopted projects as an instrument to carry out their deliveries. These companies are known as project companies and their business as project business or project-oriented business. Project business is sometimes seen as more competitive due to its flexibility. In companies producing and delivering one-of-a-kind products, projects are considered as tools to offer and produce unique products to meet the requirements of an individual customer [15].

One common factor that identifies different types of project business is the complexity of the products. The products of project companies have such complexity that they always need a certain amount of customer-specific design. Some parts of the products can be pre-designed, while some parts have to be designed according to the specific requirements of the customer. The required amount of engineering serves as a factor that separates different type's one-of-a-kind production from each other. In some cases the customer-specific engineering includes new design of some modules, while at the other end; the whole product to be delivered has to be engineered from scratch. Fig. 2 presents different categories of project companies [15].

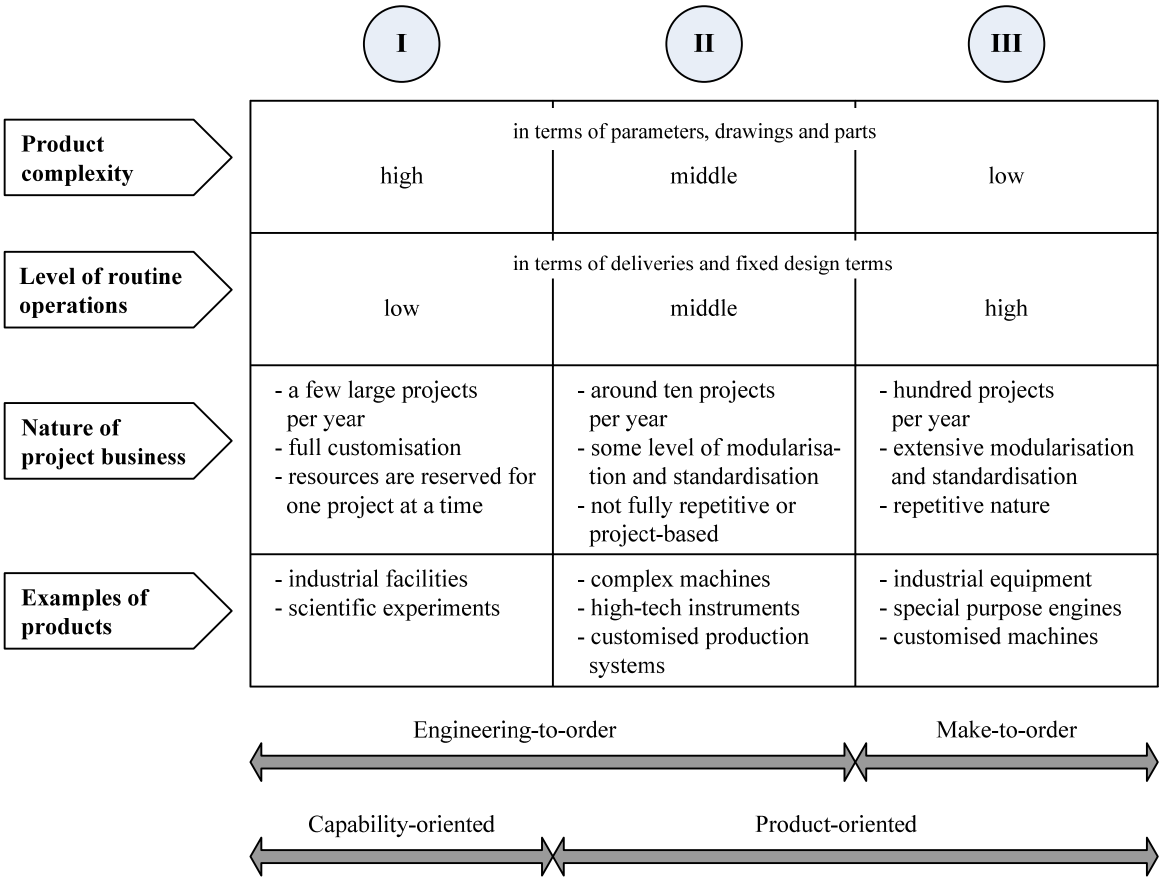


Fig. 2 Division of project companies according to project complexity

Companies in the first category (column) are traditional project companies that produce truly one-of-a-kind products. They develop a unique design each time, and deliver the product according to strict customer requirements. The second category (column) delivers technologically complex products, but they are probably able to modularise and standardise their products to some extent. When some parts of the products can be modularised and standardised, the need for customer–specific engineering is reduced and the design cycles are shortened. The last category (column) is the closest to mass customisation and mass production.

The companies in the first category can be classified as capability-oriented and engineer to order companies, and the companies in the second category as product-oriented engineering-to-order companies. The companies in the first category have only a few large projects per year, and the resources are usually reserved only for one project at a time. As the products are complex and the degree of modularisation and standardisation is low, the level of the project scope is high. The resources of the second category companies may not be allocated fulltime to a particular project, and this category of companies must manage multiple ongoing projects [15].

With modular architectures, the right configuration of the project product is constructed by uniting the customer needs with the right product features and module variations. The customer-specific requirements that cannot be satisfied with standardised architectures are determined. The required design data is specified as well as possible. This configuration is used as input in the design phase and it is usually transferred to manufacturing in the form of an order specification.

The way the sales configuration is carried out is highly dependent on the level of standardisation and the complexity of the product architectures. The more standardised the architectures, the easier it should be to specify the sales configuration. Tools built with the configuration model in are used to intensify the task of constructing the sales configuration. These tools are usually known as configurators [15].

3.3. Analysing the Degree of Modularity

After describing the terminology of product management and special characteristics of modularisation in project business, we will create a model for analysing the degree of modularity in a product. The model starts with analysing the varying needs and requirements for the products / product properties. This is important, because the products in the project business are highly customized and unique. The customers have different kinds of needs due to their different production processes. Legislation and other requirements of authorities vary from one country to another.

The second level of the analysis model is to select a certain product/component for deeper analysis. The next task is to collect basic data of the selected modules. By weighting and analysing the collected data, the different modules can be compared with each other, and the most important modules for the product can be recognised.

Finally, the horizontal and vertical commonality of the modules is analysed, evaluated and visualized. *Horizontal compatibility* means that the module can be used in different products. *Vertical compatibility* means that the module is compatible with different modules in one product. Especially in project business, due to the different needs and requirements, the modules are not fully compatible from one product to another. Modification is usually required to fulfil the given specifications and to make a module compatible with other modules in the product. The model gives an approximate analytical description of the degree of modularity and the main factors affecting it.

4. Case study

4.1. External requirements and customer needs for a product

The recovery boiler as an example has been considered in this research. In this business, many kinds of external requirements and customer needs for the selected product are met. The requirements can be presented in different categories as follows:

Customer requirements: the amount of black liquor to be handled per day; the content of the black liquor: type of the fibre line, amount of water / dry solids content, impediments, energy content, the temperature and pressure of the customers' process steam; and mill-specific standards: automation, electrification, gearboxes, pipelines, materials.

Environmental requirements: emission limitations for the flue gas, other environmental legislation, and geographical location: climate, risk of earthquakes.

Country / market area specific requirements: legislation and standards of pressurized parts, and environmental legislation.

4.2. Configuration model of a recovery boiler

The configuration model starts with a flow chart, which defines the different processes used in the recovery boiler. The function of the recovery boiler is basically always the same. The configuration of the recovery boiler continues with customer-specific needs for capacity etc., as mentioned above. Experts in sales dimension the boiler with critical process values given by the customer. The dimensioning is done with specific sales software. As a result, the software gives pre-engineered processes, and the price of the boiler can be calculated.

The dimensioned flow chart can be transformed into a pre-configured layout. Previously used lay-outs are utilized as pre-configured layouts for new boilers. The components are always quite similar in different boilers, and the detailed engineering is done with help of different types of modularity. In the detailed engineering, many external requirements affect the dimensioning of components, in addition, to customer needs. These can be for example country-specific legislation for pressured parts6 etc., as mentioned above.

As the above description of the reconfiguration model of recovery boiler shows, a recovery boiler, as a whole, cannot be considered as a modularised product. This is due to the various requirements and needs for the boiler, and therefore every boiler must be considered as unique. Despite this, modularisation can be used effectively on the main component level. In the following we will concentrate on analysing the degree of modularity on the main component level (Table 1).

4.3. Selecting the example modules

The recovery boiler consists of approximately 15 systems or processes, which include more than 100 modules. One module can be described as a functional or separately manufactured unit. The criterion for selecting the example modules was to have different kinds of modules. Also the importance for the functionality of the boiler was considered. As a result of discussions with specialists, the three following modules were selected: lower section of the furnace, the super heater, and the dissolving tank.

4.4. Analysing the commonality of example modules

The results of the analysis are presented in the Tables 1, 2 and 3. *The commonality within different boilers and compatibility with other modules is scaled from 1 to 3 types.* Arguments for evaluation are also presented. *The arrows visualize the commonality horizontally and vertically. The black line indicates high level of commonality and the broken line indicates intermediate commonality.*

Incremental cut-to-fit modularity in designing the width of the furnace is an effective and engineering time saving method. The possibilities of using this kind of modularity in designing other dimensions of this module should be analysed. To improve the efficiency of engineering even more, the positioning and shape of the openings could be standardised. Because this module requires almost 1000 engineering hours, by concentrating on improving the modularity of this module, the results in cost savings could be significant on the product level.

Table 1

Module commonality analysis (Lower section of the furnace)

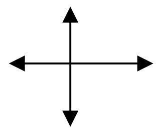
	Module commonality analysis		
	How common is the module within different boilers:	3	
	What are the major obstacles in using the same module in different boilers:	There are no major obstacles. Dimensions are incrementally cut-to-fit modularised to meet the requirements for functionality of the boiler.	
Module name: Furnace Lower Section	What are the main reasons for non-commonality:	The module must be modified because of different capacity, temperature and type of combusted black liquor.	Visualize the type of commonality
	How well is the module compatible with other modules:	3	
	What are the major obstacles in using / assembling the module with other modules in the boiler:	All assembled components are standardisedб e.g. black liquor guns and smelt spout.	
	What are the main reasons for non-commonality:	-	

Table 2

Module commonality analysis (Super heater)

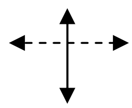
	Module commonality analysis		
	How common is the module with the similar modules in different boilers:	2	
	What are the major obstacles in using the same module in different boilers:	The shape, positioning and joints of the super heater are standardised, but dimensions (max. width is restricted), materials, order of super heaters, pipe diameters (3 standards) but amount of pipe circulations vary. The super heaters' dimensions are cut-to-fit modularised.	
Module name: Super heater	What are the main reasons for noncommonality:	Temperature and impediments of flue gas, desired steam pressure and temperature.	Visualize the type of commonality
	How well is the module compatible with other modules:	3	
	What are the major obstacles in using / assembling the module with other modules in the boiler:	The piping is different due to order of steam circulation in super heaters.	
	What are the main reasons for noncommonality:	The desired steam temperature requires different order of steam circulation	

Table 3

Module commonality analysis (Dissolving tank)

	Module commonality analysis		
Module name: Dissolving tank	How common is the module with the similar modules in different boilers:	1	
	What are the major obstacles in using the same module in different boilers:	There are various sizes (app. 20 different) and shapes (oval, round and eight) from which oval is the most common. The shell / insulation structure varies. The agitators are standardised.	
	What are the main reasons for noncommonality:	Often customers decide the shell structure. Usually it has no functional effect, but it is familiar solution for the customer.	Visualize the type of commonality
	How well is the module compatible with other modules:	3	
	What are the major obstacles in using / assembling the module with other modules in the boiler:	The smelt spout and mini hood are standardised.	
	What are the main reasons for noncommonality:	-	

The modularity of this module is at its maximum. The reasons for the horizontal broken line are different customer-specific process values. These requirements are boiler-specific and difficult to standardise. Even though the horizontal line cannot possibly be black, the efficiency of engineering could be improved by using default parameters.

The vertical commonality of this module is well arranged, because it is always compatible with its neighbour modules. Horizontal commonality does not exist, even though there are no functional restrictions [6]. The varying number of sizes, shapes and shell structures are due to customer requirements. In product policy, it should be decided which customer needs are satisfied and which not. By standardising this module into a few offered solutions, significant cost savings could be achieved due to reduced engineering hours. In some cases the engineering hours of the dissolving tank exceeds the engineering hours of the lower section of the furnace even though its functional effect on the product level is minimal.

4.5. Analysing the results

In addition to the above mentioned it can be noted that on average the modularisation is quite well arranged. Due to the complex product design and various requirements for the product, horizontal commonality is very difficult to arrange in some modules. Of the example modules, the lower section of the furnace is most effectively modularised. It is also a very important module for the functionality of the product. The advantages of modularity have been well utilized. The dissolving tank represents the other end. Its modularisation is nonefficient and there are many development possibilities [9].

5. Conclusions

1. The use of a modularity matrix helps the designer understanding the level of a product modularization and expected benefit of an agile manufacturing.

2. The considered recovery boiler design confirmed the applied methodology veracity and represented its fabricator type, when customer in early product and process development stages is strongly involved.

3. The customer activity is present from the beginning of the product design, because nothing can be manufactured in advance and the benefit of a modularisation is achieved and applied in the product engineering process.

4. The created analysis model does not give an exact value of the modularity degree, but a stepwise approach to characterize of each module has been applied.

5. When expanding the analysis to several products, it becomes more and more substantiality to weight the importance of a certain module so that the product development efforts can be focused on the most important modules.

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GAMINIO MODULINIO PROJEKTAVIMO POVEIKIS JUDRIAJAI GAMYBAI

R e z i u m ė

Gaminių modulinis projektavimas labai naudingas įvairioje gamybinės įmonės veikloje – ir gamyboje, ir kitose verslo funkcijose ir procesuose. Šiame straipsnyje pateikiamos bendros sąvokos ir metodai, naudojami gaminių vadyboje nustatant gaminių įvairovę. Pagrindinis šio straipsnio tikslas – padėti suprasti gaminio modulinio projektavimo koncepcijos svarbą. Aprašomos specialios gaminių ir jų modulinio projektavimo valdymo ypatybės. Eksperimentinėje dalyje aprašomas sukurtas preliminarus modelis, skirtas gaminių modulinio projektavimo laipsniui ir formai įvertinti. Pagrindinė straipsnio idėja – išanalizuoti ir aprašyti gaminio moduliškumo laipsnį. Galiausiai ši analizė panaudota kai kurių pagrindinių regeneracinių šildymo katilų rinkimo vienetų moduliškumui nustatyti.

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IMPACT OF PRODUCT MODULAR DESIGN ON AGILE MANUFACTURING

S u m m a r y

Modularization of products gives many benefits for different functions within a manufacturing company, both for manufacturing and for other business functions and processes. In this paper, common terms and methods used in product management and managing the product variety are presented. The main objective in this paper is to increase understanding of the concept of modularization on product design. It is described the special characteristics of the project business to the products and their modularity. In the empirical part a preliminary model for analysing the degree and form of modularisation in products is created. The core idea is to analyse and describe dimensions of the existing modularity of the product. Finally this analysis is applied to some key modules of recovery boilers.

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ВЛИЯНИЕ МОДУЛЬНОГО КОНСТРУИРОВАНИЯ ИЗДЕЛИЙ НА ПРОВОРНОЕ ПРОИЗВОДСТВО

Р е з ю м е

Модульное проектирование продуктов дает много пользы для различных функций производственной компании, как для производственных, так и других функций деловитости. В этой статье представлены общие термины и методы в управлении производством в условиях разнообразия продуктов. Основной целью статьи является повышение понимания концепции модульного проектирования в процессе конструирования продукта. Описаны особенности продуктов и их модульного проектирования. Экспериментальный случай проверен в статье как первичная модель для анализа степени и формы модульного проектирования изделия. В статье представленной идеи является анализ и описание степени модульности изделия. В результате этот анализ использован для определения модульности некоторых сборочных единиц регенерационных котлов.

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