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Investigating the applicability of modular function deployment in the process industry

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Abstract

Modular function deployment (MFD) is a recognized method for designing modular products within the discrete manufacturing industry as a means of accommodating market demands for higher variety, shorter product life cycles and smaller production batches. Nevertheless, while the process industries face similar market demands, product modularity is only sparsely explored. This paper analyzes the five steps of the MFD methodology for their fit to a process industry context based on general industry characteristics and insights from a case company. It is found that several aspects of the method must change before use in a process industrial context is feasible.

Keywords: Modular function deployment (MFD); Process industry; Product development; Complexity management;

1. Introduction

Long past is the time where companies could produce a single product variant and expect to satisfy the market at large. Today, customers are presented with an incredible product variety offered by companies striving to remain competitive by introducing new products at an ever-faster pace and in smaller production volumes [1,2]. Indeed, Bernard et al. [3] found that companies offering multiple products had higher revenues and the addition of products to a firm's portfolio likewise resulted in increased revenues. However, expanding the product portfolio in response to market demands can have adverse consequences for a manufacturing company as complexity-related costs are likely to increase in consequence [4]. In response to these challenges, many discrete manufacturers have successfully adopted platform-based modular product development approaches for a wide array of products including automobiles [2], power tools [5], and consumer electronics [6].

While the process manufacturing industry is traditionally seen as a supplier of low variety high volume products such as petrochemicals and commodity materials [7], this is a superficial perspective on an industry that is experiencing similar market trends to those of the discrete manufacturing industry [8]. Nevertheless, whereas the discrete manufacturing industry has adopted modularization and platform-based product development at large, there is comparatively sparse evidence of this in the process manufacturing industry [9,10]. Some studies have even disputed the application of established product platform development concepts in the process manufacturing industry [9], whereas others have provided examples [10,11] and anecdotal evidence [9,12] of how such concepts may be conceived.

Therefore, to further the knowledge of how modular product development can be applied in the process industry, this paper takes outset in the modular function deployment (MFD) method and analyses it with respect to process industry characteristics. MFD was selected as it has found widespread use in discrete manufacturing industry [13,14] providing credence to its applicability in practice. Furthermore, MFD is unique in that it explicitly considers business strategy [13–15], further strengthening its appeal to practitioners. These are

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contributing factors to MFD being considered a favorable approach to modular product design [16,17].

2. Modular function deployment

Modular function deployment was developed in the 1990s and documented by Erixon [15] in the first of several publications outlining the method and demonstrating its use through various cases (e.g., [14,15,18]) and examples (e.g., [13]). As a method for designing modular products, MFD is described as “a structured, company-supportive method with the objective of finding the optimal modular product design, taking into consideration the company’s specific needs.” [19] From this description it is evident that MFD has a strong focus on the practical applicability and business perspective of modularization, which is a characteristic that has been highlighted as a distinctive beneficial trait [16,17,20].

2.1. The five steps of modular function deployment

To support modular design of products, MFD utilizes a five-step process ensuring that market, engineering, business strategic, and manufacturing needs are considered [14]. The analysis required in each step is supported by one or more tools which are a combination of qualitative and quantitative approaches. The five steps are [19]:

1. Define customer requirements
2. Select technical solutions
3. Generate module concept
4. Evaluate module concept
5. Optimize modules

The first step is concerned with capturing the needs of the market or customers, which are then translated into product properties [19]. This process is supported using a modified quality function deployment (QFD) method.

In the second step, the product requirements identified through the first step are further translated into technical solutions by engineers. The technical perspective on the product is achieved through functional decomposition of the product [19]. Next, multiple alternative solutions are proposed and evaluated according to their fulfillment of defined evaluation criteria.

The third step of the MFD method is the central step in designing a modular product. Here, the strategic goals of the company are imposed on the product through several Module Drivers. Each driver represents a different strategic reason for forming a module [19]. Based on a Module Identification Matrix, technical solutions are evaluated against the set of module drivers, and several module candidates are identified.

In the fourth step, the identified module candidates are evaluated on their interface relations as well as economic impact and production performance [19]. This is supported partly by an interface matrix and a list of established evaluation parameters.

In the fifth and final step, the product platform is documented through the requirements specification of each defined module. Once this documentation is complete, development resources may pivot to optimizing individual modules subject to the specified constraints. [19]

In case non-satisfactory module performance is obtained, iterations of the design process may be required, and previous steps of the MFD are revisited. Findings from previous iterations are used as feedback to improve the design parameters and achieve better solutions [19].

3. Process industry characteristics

Manufacturing industry can broadly be divided into two sub-industries: i) assembled or discrete manufacturing industry and ii) non-assembled or process manufacturing industry (often referred to as the process industry).

Discrete manufacturing industry involves "manufacture of individual parts and components and then welding, bolting, or otherwise fastening them together into a finished product" [21]. The output of discrete manufacturing industries are discrete products, which are characterized as individual solid entities that can preserve their form without containerization [7,22]. While the output of process manufacturing industry may also be in individual units, the products are non-discrete in that individual elements are indistinguishable [23] and "often expand, evaporate or dry out" [7] resulting in them being incapable of maintaining their shape without containerization [7,22]. In general, the process manufacturing industry is defined either based on the types of products produced [24,25] or by the type of production processes utilized by the industry [7,21,26].

Although both industries share some similarities [7,27] there are several distinguishing characteristics between them, as summarized in Table 1, which may impact product development approaches. In the following sections, each of the characteristics listed in Table 1 are described and elaborated on.

Table 1. Comparison of process industry and discrete manufacturing industry characteristics. Based primarily on the findings of [7,23,27,28].

Process industry	Discrete manufacturing industry
Shallow product structure	Deep product structure
Blended formula or recipe	Assembled bill-of-materials
Few input raw materials	Many input materials/components
Frequent shelf-life constraints	Limited shelf-life constraints
Variable material grade	Predictable material grade
Frequent regulatory involvement	Limited regulatory involvement
Frequent co- or by-products	No co- or by-products
Often variable yield	Predictable yield expected
Primarily divergent product flow	Primarily convergent product flow
Material transformation	Material reconfiguration

3.1. Product structure depth

In discrete manufacturing industry, products typically have deep product structures comprised of many components and subsystems whereas process industry products are typically characterized by very shallow product structures [21]. Akkerman et al. [12] presents the case of a flour manufacturer where products are either mixed from raw materials of pre-blended and subsequently mixed, thus comprising either a single or two product structure levels, respectively. Dennis and Meredith [22] emphasizes that shallow product structures do not equal simple products. In fact, they found that yeast and bacteria manufacturing presented very complex products despite shallow product structures.

3.2. Blended versus assembled products

In many process industry sectors, input materials are combined and mixed to create a homogeneous product [24,27]. Examples include metal foundries where iron ore, coal, and other materials are combined to create homogeneous steel and metal alloys [7]. The homogenized intermediate product is often processed further through e.g., chemical, or thermal reactions before the final product is reached.

3.3. Number of input materials

Many process industry manufacturers use a single or few raw materials as input to their production processes [7]. For example, a meat processing plant uses a single source of meat to make various cutouts in different sizes, thus generating high product variety from a single material source. On the other hand, some process manufacturers rely on a relatively large number of input materials to generate their product variety [28].

3.4. Storage time restrictions

Limited shelf-life of input and output materials is frequently observed in the process industry. In food and beverage manufacturing, for example, most raw materials and intermediate products are considered perishable goods, thereby imposing a limit on the delay until further processing. [29] Most products of these manufacturers likewise have limited shelf life, which imposes an upper bound on the storage time for such products.

3.5. Material quality certainty

Process industry manufacturers rely to a great extent on materials of natural origin, which implies inherent variation in their quality [29]. In industrial bakeries, seasonal variations in flour means that gluten content varies throughout the year, which may impact product performance [30]. Stainless steel manufacturers rely mainly on procurement of scrap metal as their input material, resulting in varying material grades [24].

3.6. Impact of regulations

The process industry sector is influenced by government regulations to a higher degree than the discrete manufacturing industry [31]. In the pharmaceutical manufacturing industry, for example, regulations impose strict regulations on the products and their manufacturing processes [14].

3.7. Existence of co- and by-products

As a result of production processes used, some process industry manufacturers must manage potential additional products, which may represent a market value (co-products) or be very difficult to sell (by-products) [29]. The existence of such additional process outcomes is often visible in food and pharmaceutical manufacturing [23,29].

3.8. Product yield certainty

In some process industry sectors, production process yield is difficult to control, resulting in uncertain quality and volume of products [29]. The uncertainty of process outcomes has a potential negative impact on production management [32].

3.9. Product flow type

The production flow of many process industry manufacturers resembles a V-shape in that few input materials are processed into a relatively large number of end products [21,23]. In petroleum refineries, crude oil is separated into a range of different fuel grades and other petroleum-based chemicals [33]. Although the divergent product flow is an often-cited characteristic of process industry manufacturers, it does not apply to every company in the process industry [29].

3.10. Material change type

A main distinguishing factor of process industry manufacturers is the nature of the material transformation process. In discrete manufacturing industry, raw materials are manipulated by means of physical production processes while maintaining the original material. In process industries, materials often undergo a transformation during production, resulting in the final product being identifiable different to the input material(s). [33]

4. Modular function deployment in a process industrial context

This section compares the main elements and proposed tools for each step in the MFD method, as outlined in Sec. 2, with relevant process industry characteristics from Sec. 3. In supplement to a broader industry-focused analysis, each step of the MFD method is supplemented with relevant findings from a case company to bring additional empirical evidence to support the analysis results.

4.1. Case description

The case company is a medium-sized European manufacturer of consumer chemicals. Production is primarily performed through batch mixing, although some product groups are made by continuous production processes. The company operates primarily within the business-to-business segment and a vast majority of the products are made-to-stock to accommodate fast and frequent deliveries to customers. The company has an extensive product range of more than 1000 product variants distributed across 19 different product groups. In addition to the relatively large product portfolio, the company furthermore experiences an annual renewal rate of around 30 percent of the product portfolio. Both factors contribute to considerable complexity within product development and manufacturing and logistics operations in the company. With an aim to grow considerably in the near future, the company aims at reducing its internal complexity while maintaining the ability to deliver the increasing number of product variants demanded by its customers.

For this paper, a single product group was selected for the case study. Due to confidentiality reasons, the product group selected has been anonymized. Product group selection was done based on an analysis of the product variety across all product groups and their importance to the company from a financial perspective. The selected product group scored high on both dimensions, which was the primary reason for its selection.

4.2. Step 1: Define customer requirements

Determining customer requirements and translating these to product properties through the application of QFD has also been reported in the process industry [34–36], although it is noted that the diffusion of the method is not as high in this industry as in discrete manufacturing [35]. However, Lager [36] argues that the specifics of the process industry are not addressed by traditional QFD, citing the often-missing relationship between process industry manufacturers and end users as the primary reason. Consequently, a modified industry-specific version is proposed. As the process industry is made up of heterogeneous sectors, there may be instances where the link to the end-consumer exists, thus making traditional QFD applicable, while other situations may require use of the modified QFD approach by Lager [36].

As the case company manufactures consumer products, the modified QFD proposed by Erixon [15] was selected. It was, however, found that to encompass all the variations of the product family required by the different market segments, the Customer Value Rating matrix proposed by Borjesson [13] was more appropriate. This allowed the matrix to encompass the differences in product feature preferences across the low-, mid-, and high-end market segments.

4.3. Step 2: Select technical solutions

Translating market requirements into engineering solutions is achieved through a functional decomposition of the product. There is no correct way to perform functional decomposition [18], so several different tools are proposed to aid in this endeavor, each with a specific focus. The function-means tree hierarchically decomposes the product into sub-functions and their technical solutions, one-to-one [13,15], and is proposed for complex products, i.e., consisting of many parts [18]. However, as noted by King et al. [21] products in the process industry often have simple product structures. A hierarchical decomposition of products may therefore not be the preferred method for many process industry companies.

The aim of achieving functional independence as a precondition for good modular designs may prove difficult in the process industry sectors producing homogeneous products, as interaction between product properties exists, contrary to assembled products [36]. Functional interdependence is also observed in the product group analyzed in the case company. Here, multiple ingredients directly influence the primary function of the product. Changing one ingredient category affects the performance of another ingredient category, which may result in reduced performance of the product.

Following functional decomposition of the product, evaluation and selection of technical solutions is needed. The Pugh Selection Matrix was originally proposed by Erixon [15] for this task due to its simplicity in use. The matrix is based on several defined criteria. While the criteria are not predefined, and emphasis is placed on adapting the criteria to the specific company [19], more generic criteria are also proposed [13,18]. The industry characteristics outlined in Sec. 3, could indicate that not all generic criteria would translate equally well to the process industry. For example, this industry is typically less labor intensive [21], which would make the criteria “direct labor” less important. In the case company, a relevant selection criterion may be the compatibility of a given solution with consumer guidance labels, such as vegan or sustainability-focused ones. Other criteria could be the compatibility with existing process technologies or equipment as investment in new equipment may pose a significant expenditure.

4.4. Step 3: Generate module concept

Module drivers are the key element in MFD as they form the link between modular product development and the business’ strategy. Product strategy can be formulated across the life cycle of the product, for which reason module drivers span the entirety of this cycle [18]. Erixon [15] originally proposed 12 generic module drivers to support this. It was emphasized that the list could be supported by company specific drivers [18] or reformulated to adapt a specific company [13] and generally should not be considered an exhaustive list [15].

Erixon [18] presents the styling module driver as a module that allows aesthetic differentiation of the product without affecting the rest of the product. In the case company, a style module may be identified through the materials colorant and perfume, as these are the primary differentiators from the perspective of the customer. However, in some formulations other ingredients may have a negative effect on these resulting in e.g., discoloring or fading of the colorant.

In the process industry, product quality testing is often affected by slow microbiological reaction times [29], which may have a negative effect on production lead time. Even so, as described in Sec. 3.5 and 3.8, some process industry manufacturers are affected by either input material quality uncertainty or production yield uncertainty. In such contexts, the ability to perform testing of individual modules may result in reduced rework and product waste.

The three module drivers associated with after sales product life appear to be the generally least relevant category of module drivers. This is partly due to the inherent difficulties in performing service and maintenance on homogeneous products by replacing a module and partly because many process industry products are consumables, meaning that extending the life cycle of a product to allow prolonged use makes little sense. However, for some products such as the chemicals produced by the case company, the product function may be upgraded by mixing with other products from the company. For example, the general cleaning performance may be increased by adding a descaling product, which reduces the hardness of the water, while targeted cleaning performance may be achieved by adding a bleaching agent.

To identify module drivers for different technical solutions, Erixon [15] suggests using a questionnaire. While a questionnaire may pose an easy approach to identify module drivers, the rapid development in industrial automation and information technology since the first publication could suggest the potential for adopting a data driven approach towards module driver identification. This could especially be relevant in the process industry, as production systems in this industry are generally characterized by a higher number of sensors in production [37].

Once the module drivers have been identified, these are scored in the Module Indication Matrix (MIM). Based on the scores in the MIM, module concepts can be generated. Methods proposed for the generation of module concepts range from creative processes [19] to simple heuristics [38] to statistical methods [13]. In general, simple heuristics are proposed for simpler products, whereas hierarchical clustering is favored for more complex products. The generally simpler product structures of process industry manufacturers would suggest a bias against methods suitable for complex products.

Finally, as part of the module concept generation phase, Ericsson and Erixon [19] present a method for determining the optimum number of modules in a product. The method is based on the assembly time of the product and its modules, and the relevance to process industry manufacturers seem low. Even so, in the case company, the production of a product formulation must be done in a predefined mixing order. This may be considered somewhat analogous to an assembly sequence in discrete manufacturing, although this would require additional research to confirm whether such a comparison can be made.

4.5. Step 4: Evaluate module concept

Interface evaluation is very important to consider the overall cost of a modular design [15]. However, the presented descriptions of interface types seem heavily biased towards mechanical products given their reliance on concepts like geometry and movement.

In MFD, an Interface Matrix is proposed as a means of evaluating the module concepts and their interfaces. Ideally, either of two ideal assembly techniques i.e., the “hamburger” or “base part” technique, is sought [18,19] and all markings outside of the two ideal regions are deemed undesirable [18]. Nevertheless, the fundamental premise of the matrix seems invalid for most process industry products. This is based on the difficulty in identifying which of the assembly methods would be applied to a non-assembled mixed product such as the product group investigated in the case company. This is because while there is a defined mixing order which may to some extent resemble the "hamburger" assembly technique, chemicals reactions occur between each step resulting in the previous module(s) being transformed and homogenized. Furthermore, the implied "distance" between the assembled modules does not apply as the formulation is homogenized, in which case the assembly style resembles neither of the two ideal scenarios presented.

Once the interface evaluation has been completed, the module concepts are evaluated against several parameters [19], which are a combination of rules and metrics. Erixon [15] combines these metrics into a Modularity Evaluation Chart. While some of the proposed metrics may translate well to the process industry, such as the share of carryover, share of purchased modules and number of modules in product, others may not translate as well. A questionable parameter is the interface complexity metric due to the challenges addressed previously concerning defining and evaluating interfaces following established conventions. The material purity in modules is another example of a parameter with lower usability as most products are homogeneous and thereby uniform in nature, as explained in Sec. 3.2.

4.6. Step 5: Optimize modules

In the final step, development shifts from product architecture definition towards specifying and documenting the requirements of individual modules [13,15,19]. The importance of performing design for manufacture and assembly-based improvements to modules is emphasized. Although the method is seemingly focused on assembled products it has been used in process industry sectors as well [39], indicating that the methods and tools suggested in this step would translate well to the process industry.

5. Concluding remarks

This study has analyzed the modular function deployment method regarding its applicability to process industry products. Generally, it is found that modular function deployment in its original form may not be directly applicable for process industry products and should be adapted before use in this industry is considered feasible.

In the first step, it was concluded that QFD in its essence seems applicable although a modified approach may be needed for optimal use in process industries. Analysis of step two concluded that methods aimed at complex product structures would seemingly be less relevant in the process industry. Furthermore, the selection criteria used in the Pugh Selection Matrix cannot be translated completely to the process industry and should be adapted to the specifics of the sector and company. In the third step, the proposed methods can be used to some extent, although several of the module drivers do not fit the process industry. For the fourth step, it was found that the interface matrix is not applicable in the process industry due to the nature of the products in this industry. Some of the interface evaluation parameters likewise do not translate well to the process industry. In the final step, no major differences between the discrete and process manufacturing industry were identified.

Based on the analyses, several relevant points for further research have been identified. In step two, development of a generic set of criteria for evaluating technical solutions in the process industry could be a means of further tailoring the method to the process industry. For step three, a thorough analysis of the applicability of proposed module drivers is deemed important for the potential adoption of this method in the process industry. Investigating an alternative method for determining the optimal number of modules for non-assembled products is likewise relevant to guide product development engineers. In step four, further research effort should be directed towards the concept of interfaces in the process industry and how interface evaluation may be achieved for non-assembled products.

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References

[1] Koren, Y., *The global manufacturing revolution*, vol. 80, John Wiley & Sons, 2010.

[2] Simpson, T.W., Siddique, Z., Jiao, J.R., in:, *Product Platform and Product Family Design*, Springer US, New York, 2006, 1–15.

[3] Bernard, A.B., Redding, S.J., Schott, P.K., Multiple-product firms and product switching. *Am. Econ. Rev.* 2010, 100, 70–97.

[4] Piya, S., Shamsuzzoha, A., Miftaur Rahman Khan Khadem, M., al Kindi, M., Supply Chain Complexity Drivers and Solution Methods. *Int. J. Supply Chain Manag.* 2017, 6, 43–50.

[5] Meyer, M.H., Lehnerd, A.P., *The power of product platforms*, Simon and Schuster, 1997.

[6] Ulrich, K.T., Eppinger, S.D., Yang, M.C., *Product Design and Development*, McGraw-Hill Education, New York 2020.

[7] Abdulmalek, F.A., Rajgopal, J., Needy, K.L., A Classification Scheme for the Process Industry to Guide the Implementation of Lean. *Eng. Manag. J.* 2006, 18, 15–25.

[8] Fuller, G.W., *New Food Product Development*, CRC Press, 2016.

[9] Lager, T., A conceptual framework for platform-based design of non-assembled products. *Technovation* 2017, 68, 20–34.

[10] Meyer, M.H., Dahal, D., Managing platform architecture and manufacturing processes for nonassembled. *J. Prod. Innov. Manag.* 2002, 19, 277–293.

[11] Garcia, S., Trinh, C.T., Modular design: Implementing proven engineering principles in biotechnology. *Biotechnol. Adv.* 2019, 37, 107403.

[12] Akkerman, R., van der Meer, D., van Donk, D.P., Make to stock and mix to order: Choosing intermediate products in the food-processing industry. *Int. J. Prod. Res.* 2010, 48, 3475–3492.

[13] Borjesson, F., in:, *Advances in Product Family and Product Platform Design: Methods and Applications*, 2014, 605–623.

[14] Lange, M.W., Imsdahl, A., in:, *Advances in Product Family and Product Platform Design*, 2014, 91–118.

[15] Erixon, G., in:, Huang GQ (Ed.), *Design for X*, Chapman & Hall, 1996, pp. 356–379.

[16] Holtta, K.M.M., Salonen, M.P., in:, *Proceedings of DETC'03*, 2003, pp. 1–9.

[17] Borjesson, F., in:, *11th International Design Conference, DESIGN 2010*, 2010, pp. 147–156.

[18] Erixon, G., Modular Function Deployment: A Method for Product Modularisation. 1998.

[19] Ericsson, A., Erixon, G., *Controlling Design Variants: Modular Product Platforms*, Society of Manufacturing Engineers, 1999.

[20] Hoelttae, K.M.M., Comparative analysis of product modularisation methods. *Proceedings of Norddesign 2004,* 2004, 381–389.

[21] King, P.L., Kroeger, D.R., Foster, J.B., Williams, N., Proctor, W., Making CEREAL not CARS. *Ind. Eng.* 2008, 40, 34–37.

[22] Dennis, D., Meredith, J., Empirical analysis of process industry transformation systems. *Manage. Sci.* 2000, 46, 1085–1099.

[23] Lyons, A.C., Vidamour, K., Jain, R., Sutherland, M., Developing an understanding of lean thinking in process industries. *Prod. Plan. Control* 2013, 24, 475–494.

[24] Samuelsson, P., Storm, P., Lager, T., Profiling company-generic production capabilities in the process industries and strategic implications. *J. Manuf. Technol. Manag.* 2016, 27, 662–691.

[25] Laureijs, R.E., Fuchs, E.R.H., Whitefoot, K.S., Is more less? Benefits and costs of high-variety production in nonassembled manufacturing. *J. Mech. Des. Trans. ASME* 2019, 141, 1–11.

[26] Zhu, L., Johnsson, C., Mejvik, J., Varisco, M., Schiraldi, M., Key performance indicators for manufacturing operations management in the process industry. *IEEM 2017*, 2017, 969–973.

[27] Frishammar, J., Lichtenthaler, U., Kurkkio, M., The front end in non-assembled product development: A multiple case study of mineral- and metal firms. *J. Eng. Technol. Manag. 2012*, 29, 468–488.

[28] Finch, B.J., Cox, J.F., Process-Oriented Production Planning and Control : Factors That Influence System Design. *Acad. Manag. J.* 1988, 31, 123–153.

[29] Flapper, S.D.P., Fransoo, J.C., Broekmeulen, R.A.C.M., Inderfurth, K., Planning and control of rework in the process industries: A review. *Prod. Plan. Control* 2002, 13, 26–34.

[30] Li Vigni, M., Baschieri, C., Marchetti, A., Cocchi, M., RP-HPLC and chemometrics for wheat flour protein characterisation in an industrial bread-making process monitoring context. *Food Chem.* 2013, 139, 553–562.

[31] Kohr, D., Budde, L., Friedli, T., Identifying Complexity Drivers in Discrete Manufacturing and Process Industry. *Procedia CIRP* 2017, 63, 52–57.

[32] Fransoo, J.C., Rutten, W.G.M.M., A Typology of Production Control Situations in Process Industries. *Int. J. Oper. Prod. Manag.* 1994, 14, 47–57.

[33] Floyd, R.C., *Liquid Lean: Developing Lean Culture in the Process Industries*, CRC Press, Boca Raton 2010.

[34] Ayers, J.B., Apply Management Tools to Development Activities. *Chem. Eng. Prog.* 1999, 95, 31–37.

[35] Tottie, M., Lager, T., QFD—linking the customer to the product development process as a part of the TQM concept. *R&D Management* 1995, 25, 257–267.

[36] Lager, T., Multiple Progression — a Proposed New System for the Application of Quality Function Deployment in the Process Industry. *Int. J. Innov. Manag.* 2005, 09, 311–341.

[37] Kadlec, P., Gabrys, B., Strandt, S., Data-driven Soft Sensors in the process industry. *Comput. Chem. Eng.* 2009, 33, 795–814.

[38] Sonego, M., Echeveste, M., Fogliatto, F.S., Tonetto, L.M., ten Caten, C.S., Modular function deployment adapted. *DESIGN* 2016, 1407–1416.

[39] Kadlec, P., Gabrys, B., Strandt, S., Data-driven Soft Sensors in the process industry. *Comput. Chem. Eng.* 2009, 33, 795–814.