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ANALYSIS OF ENABLING FACTORS IN REALIZING MODULARIZATION BENEFITS

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Abstract: *Although modularization is becoming a well-described and broadly applied concept, many of today's firms still struggle to realize the promised benefits of this approach. Managing modularization is a complex matter, and in spite of this, a topic that has received far less attention compared to theories and methods concerning modularization of technical systems. Recognizing the need for guidance to realize the benefits of modularity, the purpose of this study is through a literature study and a case study to improve the insight into the organizational and systems related enablers and barriers with regard to obtaining the full potential of modularization.*
Key Words: ***Mass Customization, New Product Introduction, Agility, Modularization***

1. INTRODUCTION

Mass Customisation is a business strategy focusing on the ability to deliver individually tailored products at near the cost of mass production. Following this, mass customisation calls for customisable products which can be customised at a relatively low cost. This presents the product development process as well as the manufacturing setup with a number of challenges. One of these challenges is balancing the customisability with development and manufacturing costs since these costs, combined with the value presented to the customer, will ultimately determine the profitability of the product range. It is commonly acknowledged that the usage of modular product architecture is an efficient way of creating the product variety necessary in mass customisation [18]. Also, mass customization markets are typically rapidly changing and thus mass customizers need to constantly adapt their product portfolio to the market demands.

Due to ever shortening market life cycles and increased market dynamics, agility has emerged as a strategy widely adopted by both industry and academia. It is widely acknowledged that agility in strategy, operations and product development can be a key for company survival due to its flexibility to adapt to changing markets and industries.

Originally introduced as an operations management strategy, agility was first introduced by Goldman et al. in 1991 [8] and was by those authors defined as „delivering value to customers, being ready for change, valuing human knowledge and skills, and forming virtual partnership“ [9]. Since then, agility has been adopted in a large variety of different contexts including new product development or the new product introduction (NPI) process[20], in this context used interchangeably.

The agility or flexibility in NPI can be defined as „the incremental cost of modifying a product due to changed requirements, either internal or external to the development process“, adapted from [20]. Thomke & Reinertsen [20] identified a number of approaches that can be taken to increase the agility of the NPI process: 1) Adopt flexible technologies, 2) Modify Management processes and 3) Leverage design architecture. Within the area „Leverage design architecture“, three more specific approaches are identified: 1) Use modular product structures 2) Isolate volatility in design 3) Reduce coupling between modules.

Basically, it is stated that the use of modularity itself increases agility since a partitioning of the product design is performed; implying that if a change in product function is required this ideally only affects one module. Isolating volatility in design implies defining modules so that functions that are likely to change frequently are not implemented in the same modules as those functions considered more static, which leads to changes in fewer modules if a function change is required. Reducing the coupling between modules means designing module interfaces so that changes within one module do not require changes in other modules. It can be concluded that choices regarding product architecture and the approach taken to develop the modularity of a product is essential towards achieving NPI agility. However, as pointed out by Hansen and Sun [10], practitioners still experience difficulties implementing modular product structures and realizing the expected benefits. Based on these challenges, this paper addresses the following research question:

- *How to enable full implementation of modular product/process architecture in order to achieve agility in the process of introducing new products to the market?*

Central in answering this question is clarifying the barriers and enabling factors of a modular approach. On

this basis the following underlying research question has been defined:
- *How should enabling factors be understood and what are the causal relations between modularity benefits and enabling factors?*
- *What are the barriers and enabling factors to realize the benefits of modularization related to NPI agility?*

Barriers and enabling factors are in this context understood as the circumstances respectively hindering and enabling the benefits promised.

2. RESEARCH METHODS

In order to identify enablers and barriers mentioned above, a literature study is conducted. The purpose of this literature study is to identify and present other studies which have addressed the issue of enabling realization of modularization benefits. This literatures study is based on an extensive search primarily for recent journal papers and books. Each study identified has been evaluated for whether it addresses the link between modularization and NPI agility and thus could contribute to answering the research question. The literature study is concluded by summarising state of the art and identifying research deficiencies. Following the literature study, a case study is performed to extend the current body of research by identifying further enablers and barriers in realization of modularization benefits.

The purpose of this case study is twofold; 1) to extend/refine the existing modularization research and 2) to explore the mechanisms of realizing modularization benefits to focus future research.

These two purposes are according to Voss et al. supported by the case study method[23]. The case study is performed in one single company and is based on based on workshops and observations from new product development and introduction activities.

3. LITERATURE REVIEW

The concept of modularity and its numerous positive effects on firm performance this is not a new phenomenon and has been addressed extensively in literature [1]. In the following, the potential benefits will be reviewed followed by identification of enablers for achieving the benefits of modular product architectures.

Through several empirical studies; surveys as well as case studies, the effect of product modularity reducing the new product development time is well documented [3],[7],[13],[19]. However, industry reports that despite large research efforts the expected benefits are not always achieved.

Based on case studies [16],[5] have identified a number of different driving forces or expected benefits of modularization, termed "module-drivers". With point of departure in these [4] later introduced the Modular Function Deployment (MFD) method[1].

Also utilizing the module driver concept, Hansen and Sun [10] have introduced a modularization benefit matrix to evaluate which types of benefits a company would expect from a modularization effort and which efforts were actually experienced. In one dimension the matrix contains product development and supply chain benefits, and in the other dimension, the matrix contained direct cost, capital binding and lead time benefits. The empirical study contains 40 modularization cases in which the most common expected benefits were 1) Reduced direct cost in manufacturing and logistics 2) Reduced lead times in R&D and 3) Reduced lead times in manufacturing and logistics. Of these benefits the latter two can be related directly to agility. However, the study revealed that the benefits actually incurred much later than anticipated. Generally, after three years the benefits were not realized, but if continuing the effort the benefits would eventually be achieved. Hansen and Sun [10] furthermore introduced an incremental approach to realize modularization benefits by applying a product platform template and a modularization benefit matrix to better understand the potential benefits of modularization.

Gershenson et al. [6] have done an extensive review of models for measuring modularity of products and methods for developing modular product architectures, which naturally will act as enablers for achieving product modularity. Although several methods were identified, the approaches did not agree, which according to Gershenson et al. could be attributed to a lack of agreement on the basic concept of modularity[6].

Another extensive review within the modularity topic have been done by Jose and Tollenaere[14], identifying a great number of methods for addressing modularity issues and classified those in categories: 1) Methods, 2) Mathematical tools, 3) Algorithms, 4) Conception, 5) Representation, 6) Evaluation and 6) postponement of manufacturing approach, all aiming at enabling the implementation of product modularity.

The issue of knowledge and organizational coordination have been addressed by Brusoni and Prencipe[1], who have done an empirical study of two different industries and found that modular product architecture alone does not ensure knowledge and organizational coordination, but rather system-integrating companies should interactively manage projects to ensure that across organizational boundaries, knowledge is product interfaces are coordinated.

Using a survey, cluster and factor analyses, Caridi and Sianesi have analyzed the relationship between modularity, innovativeness and supply chain structure[2]. In this context, an interesting finding was that radically new product developments were most successful if developed in collaboration based networks whereas derivative products are most successful when developed in integrated low-collaborative networks.

The study by Danese and Filippini mentioned above also concludes that if product modularization is not accompanied by a strong interfunctional integration, this can act as a barrier towards benefits of product modularity[3].

Persson & Åhlström [17] have studied managerial issues within modularization of complex products and pointed out three management issues that must be dealt with for the modularization of complex products to be successful: 1) Decide on the appropriate degree of

[1] Modular Function Deployment (MFD is a method to find an optimal modular design taking into consideration the company's specific needs [4]

modularity, 2) Balance different functional requirements in the modularization process and 3) Coordinate the modularization process. Hence this study concludes that following an existing modularization method does not ensure success, but the management processes supporting the modular product development are crucial as well.

By reviewing literature regarding agility and modularity, it can be concluded that there are strong indications that modularity does indeed increase NPI agility. On the other hand, it can also be concluded that very few studies addresses the enablers and barriers towards realizing the full benefits of modular product architecture to increase the NPI agility. Most studies are concerned with enabling modularization through methodical development, whereas only a few study the non-methodical causes for successful modularization leading to NPI agility. The following case study contributes to addressing this gap.

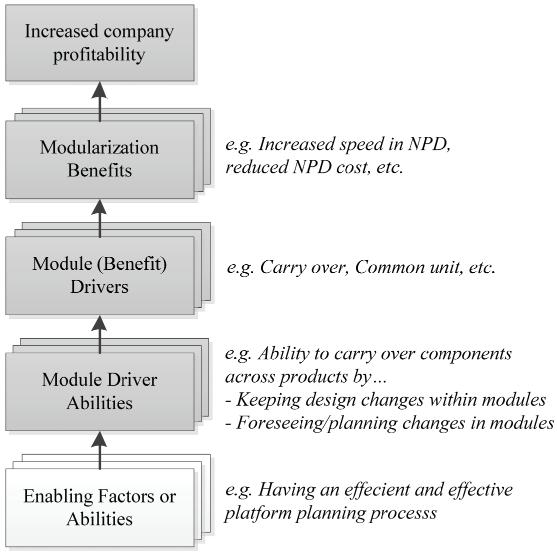

Fig. 1: Generic Cause-Effect diagram

4. ENABLING FACTORS AND CAUSAL RELATION TO MODULARIZATION BENEFITS

As argued by Hansen and Sun [10] the cause-effect relationships between modularization and the realized benefits are complex and comprehensive. Based on this the causal relation between modularity benefits and enabling factors in general is outlined to establish further clarity on how the concept of enabling factors is characterized, and to establish a sound foundation for identification of enablers and barriers of modularization benefits in the following case study.

Both **Erixon**[5]**,** Hansen and Sun [10] several others describe modularization and the benefits of this approach as an important means in increasing the company profitability, thus indicating the causal relation between modularity benefits and company profitability.

The modularization benefit matrix introduced by Hansen and Sun [10] indicates the causal relations between modularization benefits and respective module drivers also called benefit drivers. Hansen and Sun [10] further describe the causal relation between module drivers and the apparent module driver abilities, e.g. the ability to carry over components across products. Furthermore additional causal levels of abilities could be depicted based on the level of abstractions.

Enabling factors are in line with this understood as abilities or circumstances giving rise to or causing these abilities. Based on these generic causal relations between enabling factors and modularization benefits the cause-effect diagram at Figure 1 is outlined. The number of levels included in this could dependent on the abstraction level be increased.

Having the relation between enabling factors and modularization benefits defined, as well as the concept of module driver abilities defined, these are central instruments in identifying enabling factors in the following case study.

5. CASE STUDY – BARRIERS OF REALIZING MODULARIZATION BENEFITS

The case company, Vestas Wind Systems A/S, one of the largest industrial companies in Denmark, has for several years been working with modular thinking in product development. The company key drivers for working with modularization have been increasing reuse and improving product development lead time and quality. In spite of a persistent effort, the case company still struggle to harvest the full potential of modularity. The company manufactures products at a relatively high volume, and each product is configured to meet specific customer requirements and assembled based primarily on standard modules. Although focused exclusively on B2B sales, Vestas Wind Systems A/S can be considered a mass customizer.

As overall product development framework the case company has a classical stage-gate model. Each product development project undergoes as a consequence a number of stages and corresponding gates, through which the product is decomposed into first systems and then modules. The systems and system components define the functional decomposition of the products, whereas the term module is defined from a physical or value chain perspective.

As a central element in working with systems and modules the company utilizes interface diagrams. As the design is conceptualized the interface diagram are updated with the system interfaces (between the systems components) and then gradually, as the modularization process take place, the system components are divided into physical modules. These modules thus reflect the physical integration of the functional components.

5.1 Case Background

The case material is based on the experiences from a series of workshops concerning the prototype phases of product development during the spring 2012. The purpose of these workshops was to ensure a fast and efficient introduction of new product variants based on changes in existing product variants. This particular topic has gained increased attention and priority in industry in general through the last years due to the financial crisis.

The case study addresses barriers related to a mature product platform with a predefined architecture with fixed interfaces. This case study thus focuses upon the situation of utilizing the modular capability of having increased product change rates (product flexibility) without jeopardizing the associated development costs or time. Based on the case material four key themes are described in the following followed by analysis and discussion.

5.2 Case study – introduction of key themes

Theme 1 - Management of product changes.

During one of the workshops it was observed that all engineering activities, e.g. designing, structural calculations, drawing work etc., had to be finalized before being able to move further on in the development process. As depicted in the fabricated example on Figure 2, the product consisted of several sub-assemblies, each with its own assembly drawing.

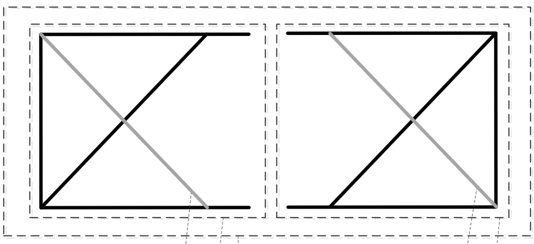

Fig. 2: Fabricated example of drawing structure

Due to the engineering approach, if e.g. a change was made in part 1.1.1 followed by another change in part 1.2.1 triggering changes in part drawings 1.1.1 and 1.2.1 as well as sub-assembly drawing 1.1 and 1.2, despite all engineering activities concerning sub-assembly 1.2 was finished, the following development activities could not be initiated before all activities concerning the 1.1 had been finalized. As a consequence starting the downstream development activities was not possible, and concurrent development thus not an option, increasing the lead-time.

Theme 2 - Unclear roles and responsibilities regarding module ownership

Based on the approach at organizing projects in the case company, for each module a specific engineer or group of engineers is appointed to have the overall technical responsibility, this setup however changing according to the project in question. Throughout the workshops it was in several cases observed that this individual or group was not being in charge of, or notified by, the changes being made in the module of responsibility. Furthermore it was in all cases observed that this individual or group only had planned for and took the responsibility for the activities within the product development function. The following downstream activities, such as prototype production was thus not planned, thought trough or within their control. As a consequence, misalignment in sequence and prioritization of engineering activities induced reflow in the process, increasing the lead-time and development costs.

Theme 3 - Interface conflicts and assembly difficulties

In one workshop two interfacing modules could not be assembled due to interface conflicts. Before initiating the prototype production the modules did not have verified interface geometry. Having fixed interfaces, and maintaining form, fit and function, this should have been possible to prevent. Furthermore the given module was complex in number of interfaces, and interface attention should thus be a basic concern for the design team. However, among others due to the size and complexity of the module, it was not checked with complete CAD modules for conflicts. One reason being limited computational power and system availability.

Theme 4 – Platform planning of product changes

During another workshop concerning product changes in one module, it was observed that change in the module interface was caused by planned product changes in interfacing module not part of the workshop. Unfortunately at the time of change in interface, all the engineering activities concerning the module in question had been more or less finalized. The changes in interfaces was thus causing reflow of varying degree and severity in the engineering process of the modules in question, with increased cost and lead times as a final consequences.

5.3 Case study - analysis and identification of barriers & enablers

Based on the case material in above, and the issues outlined, it seems reasonable to state that despite having products with modular properties, many of the expected benefits from product modularity are not a reality for the case company. This is however not the crux of the matter in this study, what instead is of particular interest are the circumstances preventing these benefits to become a reality, i.e. the barriers of realizing the benefits of modularity.

In identification of these barriers the two following perspectives having two corresponding outcomes, are identified based on among other things Millers view of implementing modular engineering[15].

One possible perspective is viewing the product as a technical system; within this perspective a general assumption is according to the theory of technical systems[12], that the structure of the system influences its behaviour. Following this line of reasoning different module behaviour could be achieved by a change in module structure. In relation to the case study, the barriers of realizing the modularity benefits could thus be argued to reside in inadequate product architecture, an account that based on the interface issues reported in the case material, cf. theme 2,3, and 4, seems reasonable. This interpretation let alone however seems questionable.

Another possible perspective is, according to the theory of design process[11], to focus on the relationship of the technical system to its environment. Given this perspective a central assumption is that the tasks of and activities in designing are influenced by several factors, one being the working means. As Miller [15] argues these other factors may as well hinder the expected behaviour of the technical system, i.e. the expected performance of the design process. In relation to identifying barriers of realizing the modularity benefits in the case study, this perspective implies that the barriers could be argued to reside in the organizational and managerial implications such as processes, systems, roles & responsibilities etc.

Acknowledging that when dealing with realizing modularization both perspectives always will co-exist, it is in identifying barriers of modularity benefits from the case material in the following chosen only to apply the latter perspective.

Managing interfaces throughout the entire development process

Interface issues as well as inexpedient or even uncontrolled changes in interface are experienced in several cases cf. theme 2, 3 and 4. As a general consequence product development lead-time is increased. This performance and module behaviour does not seem to be consistent with the expected behaviour of a system having modular attributes. The pivotal question is what is hindering stable interfaces. The answer to this question is partly to be found in the activities done to manage the interfaces, or rather the lack of management. Whereas a great effort is put in managing interfaces in the earlier development phases, by among other things utilizing interface diagrams as an integrated part of the development activates, interfaces until recently seemed to be regarded as a completed matter in the later development phases.

As the only tool or method to protect interfaces, all proposed product changes are assessed against the three criteria, form, fit and function. As long as a change complies with these criteria no change in interfaces is expected. However in some cases this assessment has failed and it is thus arguable that further support, methods or tools is needed.

Based on these observations it is suggested that managing interfaces is included as an enabling factor in realizing modularity benefits.

Product Change Management processes

It is broadly accepted that some of the basic characteristics of a technical system having modular properties is that complexity is encapsulated in modules with few and well defined interfaces allowing a decoupled and concurrent development[20]. Based on this a derived affect is as argued by among others [10],[20] that a reduced product development time is expected. This however contradicts the experienced in the case company, cf. observation 1. Based on the viewpoint that regardless of choice of product architecture this issue will remain, the solution is to be found elsewhere than revising the product architecture. By further investigation of the behaviour described in theme 1, it is revealed that the behaviour is derived from the requested engineering approach or processes, which hence is considered as an barrier, or an enabler if you like, of realizing the modularity benefits.

This line of reasoning is supported by among other Von Hippel [22] who argues that some product partitioning, i.e. architecture, is more beneficial to the development project, from which it can by deduced that correct partitioning of tasks increases development efficiency.

Having clear roles & responsibilities regarding module ownership

Theme 2 is a clear example of how the organizational setup is directly interlinked with the utilization of artefact modularization. Clear roles and responsibilities are important to any organization, and consequently, also the utilization of modularization. The example demonstrates the impact of unclear ownership and expectations related to a so-called module owner in this situation. However, this example of basic roles and responsibilities is arguably also a general discussion at all levels and functions within the case company. The specific experience one could argue is just the tip of the iceberg. Modularization entails new roles and responsibilities that are not known to the case company. In furtherance, having with people to do, and their roles and responsibilities, addresses the theme of change management and potential difficulties for an organization to unlearn present line of thinking and adapt to new roles and responsibilities.

Introducing product changes based on thorough platform planning & management

As introduced in theme 4 the detailed planning of the modular level changes is having issues with the detailed synchronization of the modular changes. The modular level roadmap was not capable of fully identifying the interrelation between the modules. This is also partly made difficult of having engineering change “spaghetti” (theme 1). Furthermore, having a relative heavy planning (manual), the constant re-planning of modular level changes is cumbersome and thus troubles will occur as in the case study. Arguably, the present confidence at product level portfolio planning and roadmaps needs to be adapted also at the modular level. Platform management by actively planning and scoping product changes is thus an important aspect in continuous improvement of a product platform as well as in realizing the benefits of modularity.

Based on the findings of the case study analysis, the practical implications is discussed in the following by utilization of key theoretical aspects from the literature review.

6. IMPLICATIONS OF FINDINGS

The motive for altogether focusing on the concept of enabling factors of modularization benefits, is by identification and acknowledgment of enabling factors, to help companies initiate focused change management efforts concerning modularization, and realizing the expected benefits hereof

Addressing the practical implications of the findings of this paper, the value of the enabling factors identified should first of all be highlighted. Knowing what organizational aspects to focus at in order to ensure an effective and effecient realization of the modularization benefits, is based on the challenges reported by industry on this particular topic found to be of high importance.

In order to benefit from the findings, it is however necessary not only to identify the enabling factors, but also for each of the enabling factors to address in detailswhich activities to initiate and how. For example; what is understood by thorough platform planning & management. It is to benefit from the findings of this paper furthermore also necessary to guide in application of the enabling factors, i.e. which enabling factors are relevant in which cases, what to focus upon, etc.

Regarding the former, it is to clarify the details of each enabling factor necessary to conduct focused and dedicated research for each of the enabling factors clarified. This will not be addressed further in this context.

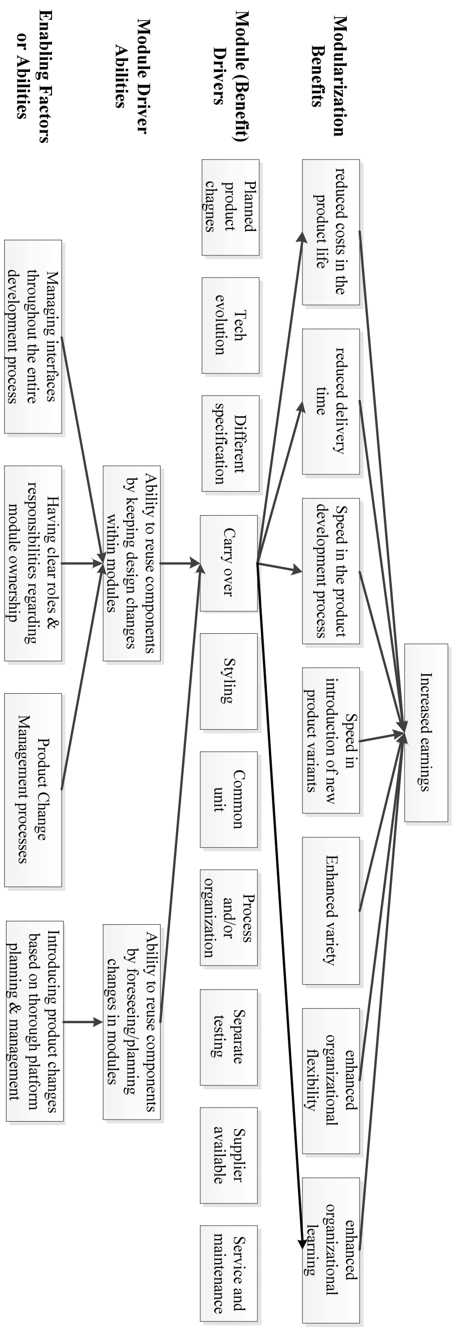

Fig. 3: Conceptual Cause-Effect tree

Regarding the latter, thoughts and preliminary ideas to guidance in selection of enabling factors is outlined in the following.

Based on the generic cause effect diagram illustrated in figure 1, the enabling factors clarified in the case study above are mapped in figure 3 together with the modularization benefits and module drivers identified in the literature review. Based on logical reasoning central module drivers abilities are also identified and mapped in figure 3 together with the relation between module drivers and modularization benefits. Based on this a causal relation between the module drivers and the respective enabling factors is established.

One of the central implications of the module drivers is in the Module Identification Matrix (MIM) which is central tool in the Modular Function Deployment (MFD) method [5]. In the MIM the module drivers are utilized in a systematic evaluation of the technical solution, with the purpose to facilitate selection of a context specific optimal module strategy.

Based on the identification of the causal relation between module drivers and their respective enabling factors, the first steps in guidance on application of the enabling factors is established. It is thus based on the outcome of the MFD-method not only possible to point at an optimal module strategy, but also possible to give direction to which change management elements to focus on, in order to realize the expected benefits of the chosen module strategy.

7. DISCUSSION

The case material is as described introductory in the case study based on experiences from product development activities concerning prototype production of new product variants that is based on changes in existing product variants.

Discussing the reliability of the findings, a subject relevant to address is the contextual circumstances of the case material i.e. whether the same enabling factors would have been identified, if case material from a different context had been utilized. Of particular relevance, is to discuss if the same enablers would have been identified if the case material had been based on another product development type.

In relation to product development types, a broadly accepted classification of development projects in; a) Research and technology development, b) platform product development and c) derivative product development has been brought by Ulrich & Eppinger [21].

Utilizing these to describe the context of the case material, the present case material context can be identified as derivative product development activities. It is thus interesting if the same enabling factors would have been identified if case material from technology or platform development had been utilized.

Given that the organization and methodologies around the different development types often are recommended to be customized it is to assume that the enabling abilities, i.e. the organizational factors enabling the realization of modularization benefits likewise is dependent on the type of development activities.

Based on this assumption the framework shown at tabel 1 is proposed. As in the case with the cause-effect tree illustrated at figure 3, the framework is presumed to be valuable in guiding in application of the enabling factors.

Table 1. *Framework for classification of enabling factors according to development type*

	Enabling factors
Technology Develop.	
Platform Develop.	
Variant Develop.	

8. CONCLUSION

Realizing the full potential of modularization in terms of NPI agility depends on other things than optimal product architecture. This paper supports this statement by reviewing central literature and by a case study in a large Danish industrial manufacturer having worked intensively with modularization for several years. Since mass customizers need to change their product portfolio continously and often rapidly and usually employ modular product architecture, these findings are highly relevant to mass customizers.

Based on a literature review it is concluded that to the best of the author's knowledge little literature addresses in detail what are the enabling factors of realizing the benefits of modularity related to NPI agility.

On the basis of central literature the generic causal relations between enabling factors and modularization benefits are identified and outlined in a cause-effect diagram serving as instrument in identification of enabling factors.

Through a case study of a mass customizer, challenges experienced in realizing the modularity benefits are described, and the underlying barriers are identified. The barriers identified were related to the following four topics: 1) Managing interfaces throughout the entire development process, 2) Product change management processes, 3) Having clear roles & responsibilities regarding module ownership and 4) Introducing product changes based on thorough platform planning & management. This paper thus contributes to modularity research by identifying four key elements in enabling the expected effects of modularization related to NPI agility.

The paper further contributes with a basis for guiding companies in application of the enabling factors.

To enhance the understanding of this topic and enable improved industry support, it seems based on the findings in this paper, both interesting and of importance, to do further research on the barriers and enablers of modularity benefits. A potential area for further research is to investigate what are the barriers and enablers of modularity benefits in other product development tasks, such as technology and platform development. Another potential area is clarifying a framework to enable classification of barriers and enablers.

As this research is part of a recently initiated Industrial Ph.D. project focusing on modularity and the NPI process, these potential areas of further research will be addressed in future work in this project.

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