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Module Drivers in Product Development: A Comprehensive Review and Synthesis

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Abstract

Modular product design is recognised as a successful approach to efficiently fulfil today's market requirements. Erixon [6] and several later publications have proposed drivers for modularising products, yet to the best of the authors' knowledge, none have attempted to unify these contributions into a coherent and comprehensive overview. Based on a review of the literature, this study has identified, analysed, and synthesised module drivers into an extensive set of module drivers. Taking outset in the value chain concept, this study identified 68 individual module drivers grouped into 29 module driver categories spanning 6 value chain steps.

Keywords: module driver; modular function deployment (MFD); modularity; product design; review

1. Introduction

With the increased fragmentation of markets into ever smaller segments, companies must be capable of efficiently accommodating this need for more variants to stay competitive. Designing products made up of interchangeable modules have proven to be a successful approach to offer high product variety at relatively low costs in a multitude of industries [e.g. 14, 7, 21, 23]. One such approach to modular product design is the Modular Function Deployment (MFD) method, originally developed by Erixon [6] and colleagues. This method is argued as being particularly useful for practitioners [8, 4, 12] and has seen successful adoption in industry [7]. The central part of this method is the generation of module candidates based on expected benefits, so-called module drivers (MDs). In MFD, product designers take outset in selected technical solutions and rate these against the MDs. The objective is to identify possible modules by integrating or isolating technical solutions. In its original form MFD includes 12 MDs spanning a typical product life cycle. [6] Since the original research on MFD and MDs, numerous studies have been published applying [e.g. 15, 5], adapting [e.g. 22, 10] or extending [e.g. 3] the method for various purposes. Despite the interest in adapting MFD, many of these studies rely on the original 12 drivers, although some propose additional drivers [e.g. 1, 20]. The addition of more MDs to MFD points to an apparent need to cover motivations for design of modules not covered by the original drivers. As these additional MDs are spread across numerous publications, researchers and practitioners embarking on a modular product design project may not be aware of these other drivers nor become aware of them without extensively reviewing the literature. While Erixon [6] has always argued that MFD should be adapted to the specific context, including the specific MDs adopted, the knowledge of practitioners and researchers may impose limitations regarding how comprehensive a set of potentially relevant MDs they may identify. Thus, to aid practitioners and researchers alike, a comprehensive set of MDs may result in both the identification of relevant drivers not immediately considered by the design team as well as facilitate probing of alternative MDs based on inspirations from such a collection of MDs.

The objective of this study is, therefore, to synthesise a comprehensive set of MDs relevant to anyone pursuing modular product design through MFD, or modular product design in a broader sense, through a review of previous research on MDs. To accomplish this, the remainder of this paper is structured as follows. Section 2 describes the methodology applied for this study followed by Section 4 which presents the findings from the analyses described in the former section. Lastly, Section 5 and Section 6 discuss and conclude on the findings of this study, respectively.

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2. Methodology

To gather and synthesise the knowledge on MDs generated since the introduction of the MFD methodology, a literature review on the subject was performed and the results analysed to form a revised set of generic MDs applicable to companies seeking to design or re-design modular products. The methodology for this study is structured according to the following major aspects:

1. Perform literature review
2. Define module driver grouping framework
3. Analyse and map MDs to individual categories
4. Summarise results as revised set of MDs

The following subsections describe the approach applied for each of the listed steps.

2.1. Literature review methodology

The literature search was done in Scopus and Web of Science using the search string "((module OR modular) NEAR/3 driver) AND product AND development". In total, 62 papers were retrieved across both search engines. Backwards reference search of selected papers produced an additional 7 results for a combined 69 papers. Following title-abstract screening of these, 27 papers were deemed relevant for further review. This set was subsequently reduced to 19 papers following full paper screening. An additional 2 papers, not identified by the literature search, were added based on the authors' knowledge of the topic. In total, the literature pool for this study comprised 21 papers. The papers were then subjected to full paper reviews and relevant module driver data was extracted and coded into an Excel database. Key data points extracted include module driver categories, MDs, and module driver descriptions. The database consists of 230 MDs from 21 papers published between 1996 and 2020.

2.2. Module driver grouping framework

The first step in the creation of a revised list of generic MDs is to define the overall framework within which the MDs are to be grouped. Whereas Erixon [7] originally structured MDs along the product life cycle, this study takes a slightly different approach by adopting a value chain perspective on MDs. The value chain was introduced by Porter [17] in the 1980s and represents "the full range of activities which are required to bring a product or service from conception, through the different phases of production [...], delivery to final customers, and final disposal after use." [9] The benefit of adopting a value chain perspective, as opposed to the original categories proposed by Erixon [6], is the closer relation to the individual steps of the product's life cycle and the corresponding organisational functions and how they might relate to product design decisions. This likewise provides a potentially greater coverage when forming module driver categories. The following generic value chain steps are adopted:

- Product development
- Inbound logistics
- Manufacturing
- Outbound logistics
- Marketing and sales
- After sales

Module drivers in the "Product development" value chain step are naturally concerned with how product design decisions may impact development activities. Likewise, the "Inbound logistics" value chain step focuses on reasons for designing modules, which may impact this aspect of logistics in the company. The same reasoning applies to the rest of the value chain steps and demonstrate their relation to modular product development decisions.

2.3. Mapping and analysing module drivers

Categorisation of the more than 200 module drivers collected was performed according to the following process: First, existing module drivers and their containing categories from literature were mapped into their relevant value chain step. Then, for each of the six value chain steps, duplicate and redundant MDs were identified and removed from the data set. Still focusing on the individual value chain step and its comprising MDs, the next step grouped related drivers to form new module driver categories. The analysis of relation between MDs was based on their focus. For example, MDs focusing on different product customisation aspects such as performance or aesthetics would be grouped into an overarching "customisation" category.

2.4. Synthesising driver categories and individual drivers

The final aspect is the combined hierarchical representation of MDs within their module driver categories. The hierarchy can be described as: a module driver belongs to a module driver category which belongs to a value chain step. Visually, this generic structure can be illustrated as in Figure 1.

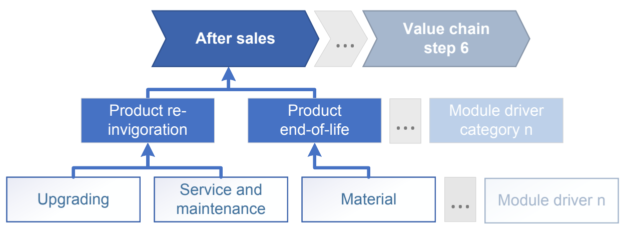

Fig. 1. A generic representation of a module driver category and individual driver hierarchy.

Figure 1 demonstrates how the "After sales" group originally proposed by Erixon [6] contains the individual MDs "Upgrading", "Service and maintenance", and "Material". These individual MDs could, for example, be consolidated into the module driver categories "Product end-of-life" and "Product re-invigoration". This hierarchical representation provides an easier overview of MDs and their relation to individual organisational aspects and facilitates a broader perspective on the potential benefits from adopting modular product designs.

3. Distribution and development of module drivers

This section presents descriptive analyses of the literature reviewed in terms of the coverage and trends of the identified module drivers. The distribution of MDs across the six different value chain steps is shown in Figure 2. It is evident that there is an uneven distribution of the number of MDs within each category. Most represented are the drivers related to Product development, accounting for 37 % of the total. This is significantly more than the second most frequent category, After sales, with 25 %. By far, the least frequent category is Outbound logistics with only one MD identified.

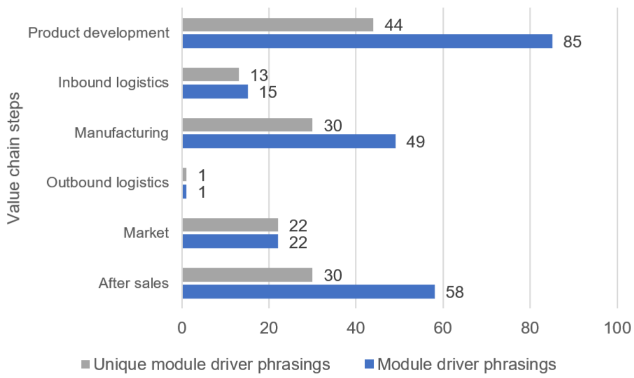

Fig. 2. Distribution of identified number and different phrasings of MDs across the value chain steps.

Figure 2 shows a clear difference between the total number of MDs identified and the number of unique drivers across the six value chain steps. This is primarily because several studies merely adopt the same 12 MDs and names as Erixon [6], even though their descriptions may vary slightly. This also implies that the value chain steps with the largest number of new and diverse MDs are the ones where the ratio between the total number of MDs and different descriptions of these is closest to 1,0. The interesting steps from this perspective are the Market and Inbound logistics categories with ratios of 1,0 and 0,87, respectively. This indicates that the MDs in these steps varies considerably more than is the case for e.g., Product development with a ratio of only 0,52.

Although it is perhaps not surprising that the frequency distribution of MDs is heavily skewed towards the Product development step, the After sales step is the second most represented, even surpassing manufacturing-related MDs. The increased focus on sustainability in recent years, would corroborate an increased attention to such aspects. Nevertheless, Figure 3 shows that despite a volatile first decade, the number of unique After sales drivers follow the trend of the other drivers relatively close over the remainder of the period covered. Consequently, there are no indications of a markedly increased attention towards this category of MDs in recent years. The relatively higher number of After sales MDs is interesting as the typical benefits, and thus underlying motivation for pursuing modular product design, relate to product development and manufacturing aspects in particular [e.g. 21, 14].

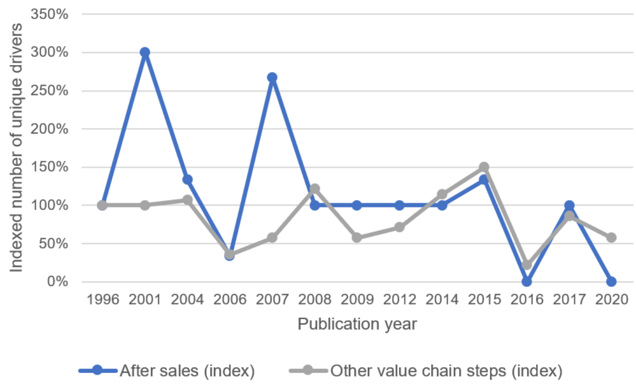

Fig. 3. The trend in rate of new module driver introductions over the period analysed. Year 1996 represents index 100.

4. A revised set of module drivers

In this section, the results from categorising and grouping MDs into existing as well as novel categories according to the hierarchical framework, shown in Figure 1, are presented.

4.1. Product development

The MDs related to product development are plentiful in literature. In total, 6 different categories comprising 16 underlying drivers have been identified:

Customisation If components are used to accommodate variety in the product based on customers' needs, forming a module from these components may be beneficial [23, 1]. This customer-driven product variety may concern different technical specifications [e.g. 6, 12, 5] or aesthetically driven attributes [e.g. 6, 3]. Variety may also be achieved along a third dimension: different functionality [11].

Technological evolution For components affected by continuing evolution of their fundamental technology, isolating these into modules may prove beneficial [e.g. 6, 16]. This refers mainly to external forces innovating technologies [e.g. 12, 1] and is furthermore relevant for risk management in product development [1].

Product planning Relates to incremental changes due to cost reductions [12, 11], performance improvements [5, 12], introduction of new product options [6, 3] or product innovation [20]. Regardless of the underlying cause, if changes are planned for components, forming modules from these may prove beneficial.

Carry-over Focuses on reusing technologies [12] or components [e.g. 6, 5] over multiple product or platform generations. Components that are feasible to re-use over time are considered beneficial and would benefit from forming a module.

Time-to-market Formation of modules from components that can be developed separately or in parallel [1] would have a positive influence on the product development lead time [11]. This may also be positively affected by forming modules from components that have similar product development lead times [20].

Regulations Components which are affected by different regulatory requirements [13], for example concerning safety [10], may be beneficial to group into modules.

Of the above-listed drivers, 13 have been proposed after the publication by Erixon [6]. These newer drivers are mainly extensions to the original driver categories, yet Regulations and Time-to-market appear as new categories. Thus, a relatively small fraction, 19 %, of drivers in this value chain step stem from the original work by Erixon [6]. This could indicate that researchers have identified additional or more specific benefits of modular product design, which may impact the development phase in particular.

4.2. Inbound logistics

The inbound logistics category represents the second least populous value chain step, with just two driver categories and three individual drivers.

Strategic supplier available The use of a trusted [23] or strategic supplier which may possess specific capabilities or can take advantage of developing and/or manufacturing complete modules can be beneficial [e.g. 6, 12, 3].

Purchasing Dealing with a single large supplier rather than multiple smaller ones for components may reduce administrative costs associated with purchasing and logistics [6, 5], thus grouping components into modules delivered by a single supplier may be beneficial.

Among the 57 % of papers in the study mentioning the use of strategic suppliers, there is considerable consensus of the focus of this MD. All descriptions appear as variations on the same theme i.e., to outsource development and manufacturing of multiple components and in return purchase a single complete module. Only Erixon [6], and later Borjesson [5], note the potential for reducing administrative and logistics costs associated with sourcing complete modules from suppliers.

4.3. Manufacturing

Related to manufacturing, 8 different module driver categories and 15 individual drivers were identified, covering various aspects such as quality assurance, processing capabilities, and inventory management. The MD categories and individual drivers are:

Common process Components that rely on a similar manufacturing technology [11, 25] or process [6] may benefit from being combined into a module. This may also apply to components for which the work content is suitable for a group or team [12, 6].

Common unit If components can be used across the entire product assortment, improved economies of scale in manufacturing are expected [11]. Consequently, forming modules from such components would be beneficial [e.g. 6, 23, 16, 5].

Separate testability Individual and separate testing of product functions prior to product assembly is considered beneficial [e.g. 6, 12, 1] and is thus a driver for forming modules to facilitate product quality assurance.

Special process requirements For components that require special handling, skills, tools [2], or processes [16, 2], isolating these to individual modules may prove beneficial.

Automation If automated assembly of components is possible, grouping these into a module may facilitate automated production [6, 2].

Production lead time For components which have a significantly longer lead time than average, delegating these to an individual module may prove beneficial [6, 2].

Storage If components have special storage requirements forming a module from these components may be beneficial [2].

Late differentiation point If components may be used to differentiate the product late in the production process, forming a module from these would facilitate delayed differentiation strategies [1].

Of the above-listed drivers, almost half, 47 %, are not mentioned by Erixon [6], yet most fall under existing MD categories. Only Storage and Late differentiation point are new driver categories.

4.4. Outbound logistics

For outbound logistics, a single MD and driver category has been identified.

Transportation Wee et al. [24] suggests transportation of components as a MD. It would be beneficial to form modules from components which have similar transportation requirements.

This value chain step is sparsely covered in literature, as indicated by the single MD and single source. The MD relates originally to construction industry [24], yet no definition of the driver is presented. It would, however, be expected that this driver could see use in industries using hazardous materials or physically large structures.

4.5. Market

Market-related MDs are divided into 7 driver categories comprising 17 individual drivers, covering different demographic parameters.

User perception Similarities in attitude or loyalty towards a product, or perceived benefits [16] of said product, can provide beneficial reasons for forming modules from product elements. [18]

User geographic Consumer needs may differ depending on their specific area, region, or even the size of the city they live in. Thus, forming modules based on groups of consumers sharing similar geographical features can be beneficial. [18]

User skills Grouping elements based on the proficiency of users may provide benefits. The proficiency or skills of a user can be related to their level of instruction, use frequency, or knowledge level of the product. [18]

User biologic parameters It may be beneficial to form modules from elements for which users share age or gender [18].

User social status The social status of a user may provide basis for beneficial grouping of product elements. The social status of a user can be related to their occupation, life style, or life cycle phase. [18]

Culture and tradition The specific culture or traditions of users may provide a beneficial basis for grouping product elements. [18]

User financial status Grouping product elements based on the income of users or their households may prove beneficial. [18]

Whereas the Inbound logistics category had widespread recognition in literature, but only few drivers, the Market category appears opposite as this category is comprised of only two papers with a relatively high number of proposed MDs.

4.6. After sales

The following 5 driver categories and 16 individual MDs related to After sales have been identified:

Material recycling Forming modules from components may be beneficial in relation to recycling for different reasons. Drivers include similarity of type [12, 1], compatibility [25, 26, 6], value [3], hazardousness [6, 12] or recyclability of component materials [6, 26].

Service and maintenance Components considered wearing parts could benefit from being grouped into modules. The main drivers are to facilitate replenishment [1], maintenance [6, 11], or repairs [1, 6, 5].

Upgradability Performing after-market upgrades on a product is facilitated if relevant components are grouped into modules [1, 6]. Such product upgrades relate mainly to product performance increases [5, 12, 3] and may be achieved through changing existing modules [5] or by adding additional modules [1].

Component re-use Not all components in a product wear at the same rate. For components with a similar service life in excess of the product they are embedded in, grouping them into modules may be beneficial [25, 26]. This is related to re-use of the components in other products [1], either directly or following re-manufacturing [26]

Component disposal Components which are to be disposed at product end-of-life, may benefit from being grouped into modules. Drivers include components destined for incineration [1] or landfilling [1, 20].

Despite nearly half, 43 %, of all papers reviewed proposing unique MDs related to After sales, a majority of these can be considered extensions of categories already proposed by Erixon [6]. Even so, the two categories Component re-use and Component disposal represent different perspectives on After sales MDs. While Erixon [6] focuses on recycling of materials, the Component re-use drivers consider re-use of complete functional units in other products, e.g., through re-manufacturing of automotive turbochargers [19] or re-use of mobile phone subsystems [20].

5. Discussion

This section present discussion related to the results from Sections 3 and 4, as well as the methodology, described in Section 2, from which this study was realised.

In relation to Market-related MDs, these can perhaps be argued to simply be variations or elaborations on drivers from the Product development step, such as technical specification or styling. Nevertheless, these Market-related MDs present a more nuanced perspective than the drivers in the product development category. Moreover, as any successful product development project relies on integrating various functions within a company, including sales and marketing, these tailored MDs may assist in translating product design motivations and potential impacts across department and professional boundaries.

The search string applied has focused on papers explicitly focusing on drivers of modularity. This has produced a relatively limited amount of papers, despite the general amount of literature concerned with modular product design. It can be argued that an alternative search string utilising a broader perspective on drivers - or perceived benefits - of modularity would have produced a larger body of search results. For example, Mogensen et al. [15] investigated the applicability of MFD in the process industry and found that certain industry specific drivers might exist. It is, therefore, reasonable to suggest that additional MDs could be identified by focusing on different industries.

The aim of this review and synthesis of MDs for product development was to be relevant for both practitioners and researchers. In this perspective it can be argued whether the number of MDs identified would be infeasible for any product development projects, as the resources required to evaluate product designs against all MDs could prove prohibitive. It is, therefore, believed that to better support product designers a structured and efficient method for delimiting large sets of MDs should be investigated.

6. Concluding remarks

This study has identified, analysed, and synthesised a comprehensive set of module drivers (MDs) across organisational functions, which may impact product development decisions and is, to the best knowledge of the authors, the first study to contribute this.

In total, 68 different drivers of product modularity were defined and categorised. To encompass as broad a scope of potential impacts from modularising products, the MDs were categorised according to a generic value chain, comprised of 6-steps ranging from Product development to After sales. The number of MDs identified per value chain step was between 15 to 17 for all but the Inbound and Outbound logistics steps, which produced just 2 and 1 MDs, respectively.

Researchers and practitioners alike interested in modular product design may take outset in this comprehensive set of MDs when investigating potential benefits from modularising products across organisational functions. The value chain perspective on MDs enable practitioners to focus and prioritise their efforts by quickly relating design decisions to organisational functions, thereby facilitating: (1) identification and selection of stakeholders to include in the design process and (2) rapid delimitation of the comprehensive number of MDs identified.

Furthermore, the relatively high discrepancy in number of MDs for the six value chain steps may point to interesting areas for further research into potential impacts from product design decisions for the related organisational functions.

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