Strategic Reasons for Modularization

Implications of having a modular product architecture

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CAROLINE SVENSSON
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by

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Strategiska Nyttigheter med Modularisering

Följder av en modulär produktarkitektur

av

Linnea Gimbringer
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Abstract
Customers of today have high requirements on what products they choose to purchase. Modularization is a business strategy, which aims to increase the possibility of offering different variants of a product to meet high standards and varying demands of customers. With new regulations, advancements in technology and newly discovered customer needs, the growth in complexity of manufacturing companies’ product architecture is a natural result. The request from Scania, which is the commissioner of this master thesis, was therefore to enable for research and development (R&D) to make conscious decisions that support that the modularization is maintained over time. With this as a starting point the purpose of this thesis is an investigation of what strategic reasons R&D should consider to make conscious decisions aligned with the modularization principles during product development projects.

We have conducted a case study, including a literature review and semi-structured interviews, to understand the modular product architecture and strategic reasons for modularization. The semi-structured interviews have been conducted firstly internally at Scania but also with two external experts within modularization.

The results suggest that the bygglåda (toolkit) is what characterizes the modular product architecture at Scania. The toolkit exists to develop the modular system from which products can be created and configured through modules or components. This modular product architecture has certain implications on product change, product variation, component standardization, product performance and product development management. The results further suggest that corporate strategies can be broken down into strategic reasons for applying modularization, which are linked to the different phases of a product lifecycle. R&D seems to play a central role, regarding Scania’s company specific strategy of meeting a high variation in customer needs, where the strategic reasons are technology evolution, planned product changes, common unit, carryover and separate testing. Eventually, a conceptualized example of the powertrain showed that strategic reasons are also module specific. The results of understanding the different characteristics of the modules is important when developing modules at R&D as the classification of modules can function as base for decision-making during development projects. Knowledge about the characteristics of a module can indicate what is allowed and what is not allowed to change for the specific module.

Keywords: Modularization, Strategic Reasons, Modular Product Architecture, Module
Sammanfattning

Vi har genomfört en fallstudie, genom en litteraturstudie och semistrukturerade intervjuer. De semistrukturerade intervjuerna hölls främst internt på Scania men utöver detta hölls intervjuer med två externa experter inom modularisering.


Nyckelord: Modularisering, Strategiska Nyttigheter, Modulär Produktarkitektur, Modul
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## Terminology

*This section presents key terms that are used in this report.*

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<th>Term</th>
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<td>Functional element</td>
<td>a desired function that aims to fulfill the customer demand</td>
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<td>Physical Component</td>
<td>a physical entity that embodies a product property and generates a function</td>
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<tr>
<td>Module</td>
<td>a functional building block, with specified and standardized interfaces, chosen for company-specific strategic reasons</td>
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<tr>
<td>Module Variant</td>
<td>a physical realization of a module that has a clear function, which serves a purpose for the end product to function</td>
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<tr>
<td>Component</td>
<td>a separable part or subassembly</td>
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<tr>
<td>Module Drivers</td>
<td>means by which the business corporate intent can be applied to the product</td>
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<td>Modular Function Deployment</td>
<td>a method for finding the optimal modular product design based on the company’s specific needs</td>
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<td>Module Indication Matrix</td>
<td>a matrix that enables identification of modules by analyzing the relationship between the technical solutions and the module drivers</td>
</tr>
<tr>
<td>Variant Part Tracking</td>
<td>a framework for tracking number of parts in relation to the number of variants</td>
</tr>
<tr>
<td>Bygglåda</td>
<td>a toolkit containing all pieces available at Scania to create a complete transport solution</td>
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Foreword and Acknowledgement

This report presents our master thesis, which is the final step in our Master of Science within Industrial Management. The work has been conducted within the department of Industrial Management at the Royal Institute of Technology and Scania has been the client.

First of all, we would like to thank all respondents for kindly sharing their expertise and for taking the time to participate in the interviews. We would also like to thank the members of the reference group at Scania, for participating in the reference group meetings and making sure that this study is of value to all stakeholders.

Eventually, we would like express our gratitude to our supervisor at Scania, Jesper Yu, and our supervisor at KTH, Bo Karlson, that have provided guidance during the project by contributing with valuable insights and feedback.

Thank you all!

Linnea Gimbringer & Caroline Svensson
Stockholm, June 2017
1. Introduction

In this chapter we first clarify the background to the case, followed by a brief description of the underlying phenomenon of the problem. Furthermore, the purpose and research questions as well as the delimitations of the study are stated.

1.1 Background

Customers of today have high requirements regarding what products they choose to purchase. New markets, new regulations and new technology imply a continuous change of the operating environment (Scania CV AB, 2011). During the last decades the complexity of products and systems has been increasing, both due to more specific customer needs but also due to a shorter lifetime of products (Bullinger et al., 1995). Thus, an important challenge for manufacturing companies operating in the automotive industry is to understand the diversity in customer needs and incorporate it in their product range (Scania CV AB, 2011).

Modularization is a business strategy, which aims to increase the possibility of offering different variants of a product to meet the high standards and varying demands of the customers (Scania CV AB, 2011). The aim is to realize new demands, from either customers or new regulations as quickly as possible to a reasonable cost, without an unnecessary increase of unique parts.

Scania CV AB is a major Swedish automotive industry manufacturer that delivers customized heavy trucks, buses, engines and services (Scania CV AB, 2011). The company’s history of using modularization as business strategy stretches far back in time. As the technology advances and new customer needs are being discovered, the growth in complexity of Scania’s product architecture becomes a natural result of that development. Furthermore, the modularization is described as vital for Scania’s success and it is therefore crucial that the daily activities are in line with the company’s principles of modularization. As of today, there is an increased demand from research and development (R&D) for relating the daily work to modularization in a systematic way.

Scania was acquired by Volkswagen in 2014, and is consequently a part of the Volkswagen Group. Under the umbrella of Volkswagen, MAN is another company operating in the commercial vehicle industry. Scania and MAN will be cooperating within certain areas and there will be a utilization of synergies between the two different companies (Volkswagen AG, 2016). As of today the companies do not have a coherent view on modularization and product structures. For that reason, Scania needs to have a systematic approach towards the modularization. This could also support different decisions made within the Volkswagen Group. All in all, to be able to utilize synergies it is key that Scania is able to communicate
what the development of new products looks like, how the company is making decisions and why.

The product development processes within Scania consist of four main phases and is based on continuous flow and improvement. Scania needs to make decisions during these development phases that do not jeopardize the company’s modular system. Thus, Scania needs to know what to base these decisions on, to be able to determine whether to proceed with different development projects or changes to the product architecture.

1.2 Problematization

New markets, regulations and technological shifts increase complexity within Scania’s product assortment. In order to offer customized products, of highest quality while at the same time keeping costs at its minimum, Scania is using a modularized product architecture. The increased complexity within Scania’s product assortment means an increased demand to be able to maintain the modularization over time. Research and development (R&D) needs to make conscious decisions that support that modularization is maintained over time. As of today, it is uncertain what factors are affecting modularization and what is considered good modularization. Therefore, the phenomenon studied in this thesis is what implications a modular product architecture has as well as the strategic reasons for modularization at Scania.

1.3 Purpose and Research Question

The purpose is to investigate what strategic reasons R&D should consider in order to make decisions aligned with the modularization principles during product development projects. The following research questions are a deconstruction of the purpose. To fulfil the purpose, we first need to answer RQ1, which focuses on how Scania is applying the concept of modularization and what implications such architecture has. The following questions both exist to answer the question why Scania is applying the concept of modularization, which is key in order to fulfil the purpose of knowing what strategic reasons R&D should consider to make decisions that support that the modularization is maintained over time. While RQ2 addresses what the company intends to achieve along lifecycle, RQ3 addresses the module-specific strategic intents.

RQ1: *What are the key characteristics that define a modular product architecture at Scania, and what are the managerial implications of having a modular product architecture?*

RQ2: *What is the most important corporate strategy for applying modularization at Scania and what are the strategic reasons for applying modularization along the lifecycle phases?*

RQ3: *How are different modules related to different strategic reasons for modularization at Scania?*
1.4 Delimitations

This thesis is based on a case study conducted at Scania and concerns the heavy truck segment. Some external experts have been involved in the study, but the empirical data have been gathered mainly within R&D at Scania.

Modularization as a concept can be applied to physical products, software as well as to organizational structures. However, this study has been delimited to modularization of physical products.

1.5 Outline

The remaining part of this master thesis report consists of eight chapters. Below is a brief description of each chapter.

**Chapter 2 - Literature Review** Concepts and definitions regarding modularization is presented and described in this chapter. Also, one method for developing a modular product architecture is introduced in this chapter.

**Chapter 3 - Scania’s Way of Working** This chapter introduces Scania’s way of working with modularization. Scania has three modularization principles which all are presented as well as what methods Scania uses to govern the modularization principles.

**Chapter 4 - Methodology** This chapter begins with a presentation of the research design. After that the data collection methods are presented and motivated. Finally, the quality of the research method is discussed with regard to reliability and validity.

**Chapter 5 - Product Architecture** This chapter presents the results and analysis related to the modular product architecture at Scania. Later on, different implications of having a modular product architecture is discussed.

**Chapter 6 - Strategic Reasons for Modularization** Results and analysis regarding strategic reasons for modularization on a corporate level is presented in this chapter. The strategic reasons for modularization are derived to one of the different phases of the product lifecycle, which are R&D, Production, Customer and Aftermarket.

**Chapter 7 - Strategic Reasons in Different Modules** This chapter presents the results and analysis regarding strategic reasons on a modular level. A conceptualized example of the powertrain of a truck is also presented in this chapter. All five modules, which form the powertrain have been classified with regard to the strategic reasons for modularization.
**Chapter 8 - Conclusion and Further Work** In this chapter the conclusion for this thesis is presented. The conclusion connects the results and the purpose of this thesis. Future research is also discussed in this chapter.

**Chapter 9 - Discussion** The last chapter contains a discussion of the research analysis and the conclusions drawn. More specifically we discuss the research analysis and how the conclusions drawn impact modularization both in general and at Scania.
2. Literature Review

In this chapter follows literature, which has been used for understanding the empirical data that has been gathered. First, we present our choice of definitions regarding modularization that will be used in this report. Second, we clarify the characteristics and implications of a modular product architecture. Thereafter we present the purpose of modularization, followed by constraints and strategic reasons for modularization. Finally, we declare methods for implementing modularization.

2.1 Modularization and Definitions

Modularization is a way to achieve a large product variation to meet various customer demands. Ericsson and Erixon (1999) argue that this can be done by fulfilling two main characteristics. First, by a “similarity between the physical and functional architecture of the design” and second, by a “minimization of the degree of interaction between physical components”. Based on these two characteristics the following definition of modularization applies:

“Modularization is a decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific strategies.”

By the definition of modularization, Ericsson and Erixon (1999) emphasize the fact that companies pursuing different strategies will have differently modularized products. The strategy aspect implies a difference to a modular architecture, which only regards the actual architecture of the product, defined by Ulrich (1993) as:

“1) the arrangement of functional elements; 2) the mapping from functional elements to physical components; 3) the specification of the interfaces among interacting physical components.”

There are different ways of defining a module in the literature. There is a recurring ambiguity, which regards whether a module is something physical, such as a composition of parts, or if a module is related to functions and specifications of certain attributes. In this report we define a module, in consistency with (Modular Management, 2012a) as:

“a functional building block, with specified and standardized interfaces, chosen for company-specific strategic reasons.”

This implies that we will not refer to a module as a physical unit, but rather a set of rules, which can be documented in a module specification. An object that complies with the rules of the module specification is called a module variant. A module variant is a physical realization of a module that has a clear function, which serves a purpose for the end product to function
Module variants are connected through *interfaces*. Interfaces are also boundaries between *components*, which we in this report define in consistency with Ulrich (1993) as a separable part or subassembly. The interfaces furthermore describe how components depend on each other (Scania CV AB, 2011).

### 2.2 Modular Product Architecture

Choosing the product architecture is key regarding the performance of a manufacturing company. Ulrich (1993) defines the product architecture to be: “(1) the arrangement of *functional elements*; (2) the mapping from *functional elements* to *physical components*; (3) the specification of the *interfaces* among interacting physical components”. Eppinger and Browning (2012) give a similar definition by describing three different mappings. First decomposing the product into modules and components, second assigning different functions to the modules and components and third the interaction between module variants and components.

All functional elements within a product build up the functional structure of a product. Each functional element is representing a certain function of the end product (Dieter & Schmidt, 2013). The functional structure also shows how the functional elements are arranged and how they interact with each other (Ulrich, 1993). Examples of functional elements are stability of load, comfort for occupant, transfer engine torque, steering or braking.

The relation between physical components and functional elements is that functional elements are implemented in the product by physical components (Ulrich, 1993). Physical components and functional elements can either have a one-to-one relationship, a one-to-many relationship or a many-to-one relationship. As an example within Scania, the functional element of transferring engine torque is enabled by the propeller shaft within the truck. This is a one-to-one relationship visualized in Figure 1.

![Figure 1. One-to-one relationship between physical component and functional element](image)

According to Ulrich (1993) a modular architecture must have a one-to-one relationship between physical components and functional elements. However, in manufacturing companies this is not always the case. An example within Scania, which has a one-to-many relationship, is the noise encapsulation and the functional elements of sound attenuation and heat insulation, visualized in Figure 2. The functions of attenuating sound and insulating heat are both implemented by the physical component noise encapsulation.
Figure 2. One-to-many relationship between physical component and functional element

Ericsson & Erixon (1999) argue that a product architecture can be divided into three levels: product range level, product level and the component level. There are two fundamental types of product architectures which can address these three levels; modular architecture and integral architecture (Dieter & Schmidt, 2013). The difference between the modular architecture and the integral architecture, is the relations between the functional elements and the physical components (Ulrich, 1993). In addition to the one-to-one relationships between functional elements and physical components, a modular product architecture must have decoupled interfaces, meaning that interfaces between components are not dependent on each other. The opposite of decoupled interfaces is coupled interfaces, which means that the interfaces are dependent of each other. As an indication, two components are coupled if a change in one of them requires a change in the other, in order for the entire product to work as it is intended to. The dependency in coupled interfaces makes it more complicated to control and more difficult to change, compared to the decoupled interfaces.

At Scania, the frame within the chassis is a component with decoupled interfaces (J. Yu, personal communication, March 23, 2017). The standardized interface allows a variety in terms of placement of physical components, which are to be attached to the frame. The opposite would be predetermined attachment of physical components, which would not allow a change in one component without changing the intended function of the entire product. This is an example of coupled interfaces.

In reality, it is complex task to achieve a decoupled design since the interfaces between components or module variants usually depend on each other (Ulrich, 1993). To some extent, it is a matter of the level of detail the components and elements are considered, in the functional structure. Certain interactions may also be more difficult to define than others (Eppinger & Browning, 2012). For example, simpler contact interfaces, are more easily defined than more uncertain conditions such as vibrations or heat transfer. The implications are that you have to set limits that are acceptable. Weighting certain interactions depending on their function is usually a complex task, but can be achieved by considering the interactions collectively as well as separately.

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2.2.1 Implications of Product Architectures

Ulrich (1993) argues that the product architecture has different implications on different areas important for manufacturing companies and that there is a linkage between product architecture and areas of managerial importance. Defined by Ulrich (1993) these areas are product change, product variety, component standardization, product performance and product development management.

Product Change

Product change is an important area to a manufacturing firm (Ulrich, 1993). Planned change can occur for several reasons, for instance due to an upgrade, add-ons, adaptations, shift in customer demand or due to new legal requirements. The magnitude of change can vary from changing a single component to changes across generations of products. Product change and the ease of which a change can be implemented, is directly linked to the product architecture. Depending on what product architecture the company applies, changes may have different implication on the product.

A modular product architecture allows changes on a component level without having to change any other components or modules (Ulrich, 1993). This is due to characteristics of the modular product architectures of having one-to-one relationships between functional elements and physical components, and the decoupled interfaces. Change on a component level in an integral product architecture, on the other hand, requires change of the entire product.

A company’s ability to implement changes across product generations is also linked to the applied product architecture (Ulrich, 1993). A modular architecture enables reuse of components across generations. Desired change can, because of the modular architecture, be focused around a specific component of the product. As an example, Scania was able to make changes to the suspension and at the same time reuse the axles across the new generation of trucks (J. Yu, personal communication, April 6, 2017). Since there were no new requirements in terms of the axles’ performance, the axles could be reused. Change across generations of a product with an integral product architecture requires changes to multiple components in the product.

Product Variety

The demand for product variety has increased during the last couple of years. Product variety has therefore become an aspect that affects the competitive advantage of a manufacturing firm (Kotha, 1995). High variety in product range refers to the variation in functionality among products in a production system (Ulrich, 1993). This may be offered from both modular and integral product architecture; it is really a matter of cost. Product variety is technically feasible for a manufacturing company with an integral product architecture by, for instance, developing different variants for each model. Such a system will, however, result in a large number of components in the production system and it might be unreasonably expensive. The
challenge for a manufacturing company is to economically produce product variety. A system that enables economical product variety is considered flexible. Unlike the integral product architecture, a modular architecture is in its nature considered flexible. The reason for this is that it allows configurability between different components of the product due to the one-to-one relationships between function and physical component and the decoupled interfaces. A modular architecture also requires far less components in the system compared to an integral architecture to create the same product variety.

**Component Standardization**

Standardization and modularity are often perceived to be each other's opposites (Simpson et al., 2006). However, some mean that the concept of standardization and its fundamental meaning, which implies mass production of a product or component with a common design, has an impact on modularity to some extent. Unlike the strategy to standardize an entire product, standardization can be utilized in a module architecture on a component level. Standardization on a component level should, in other words, not be confused with standardization on product level. Component standardization can be described as the use of the same component in multiple products and is linked to product variety (Ulrich, 1993). Standardized components are used to improve efficiency in production, quality and also to reduce costs (Gershenson et al., 2003). Tires, bearings, frames and screws can for instance be standardized components in a module based product architecture. However, a component can be standardized if and only if the component implements commonly useful functions and if the interface to the component is identical across more than one different product (Ulrich, 1993).

**Product Performance**

Product performance refers to how well the product fulfills the desired functionality. Product performance characteristics for a truck can be speed, fuel consumption, comfort and life. Ulrich (1993) separates local product performance from global product performance. Example of local product performance is the intensity of the rear lamp or adjustable seats. Fuel consumption is an example of a global product performance since it is affected by multiple product properties such as the weight of the entire truck and to what extend the design is aerodynamic.

A modular product architecture enables optimization of local product performance through component optimization (Ulrich, 1993). This is allowed, again, due to the one-to-one relationships between function and physical component and the decoupled interfaces. Module variants’ performance can be optimized through separate design, testing and refinement as the modular architecture allows changes without having to take adjacent components into consideration. A modular variant may be developed or optimized with an integral design, this however requires a clear definition of how far the modular architecture extents.
An integral architecture allows optimization of the global product performance (Ulrich 1993). Optimization of the global performance such as fuel consumption, acceleration and load capacity is most often affected by the size and the mass of the product. Function sharing is one way to optimize size and mass, meaning that one physical component fulfills multiple desired functions. In theory this creates a coupled design and many-to-one relationships between functions and physical components, which creates an integral product architecture. Therefore, optimization of size and mass is done at the expense of the modular design.

**Product development management**

The product architecture has implications on the different phases in the product development process (Ulrich, 1993). Assuming that the product development processes consist of the four phases (1) concept development, (2) system level design, (3) detailed design and (4) product test and refinement, the product architecture has the largest implication on the last three phases of the process.

The system level design implies development of the product architecture and assignment of component development tasks. An integral architecture requires less emphasis on this phase in comparison to the modular architecture. This since the modular architecture requires well defined and well documented interfaces. The detailed design phase concerns detailed component design, testing and production process planning. This phase of the development process forces a company with an integral architecture to focus on communication and interaction between design teams, which is mainly due to the coupled interfaces in an integral architecture. A modular architecture, on the other hand, enables independent or parallel detailed component design and testing through decoupled and well defined interfaces. The last phase, product testing and refinement, is also affected by different implications with regard to product architecture. A modular architecture allows separate testing of module variants. It also enables changes to only one or two module variants if a product performance must be changed. An integral architecture requires changes to many components in order to refine a product.

2.3 Purpose of Modularization

Traditionally there are three different strategies, which companies can use to differentiate themselves: product leadership, operational excellence and customer intimacy (Treacy & Wiersema, 1993). Success within one of these strategies usually occurs at the expense of the other two, which is not optimal (Maylor, 2010). The purpose of modularization is to enable companies to be successful within all three traditional strategies, which is visualized in Figure 3. Despite that, all companies must know what their main company specific strategy for modularization is.
2.3.1 Product Leadership

Product leadership refers to offering a continuous stream of leading-edge products to the customer (Treacy & Wiersema, 1993). These products are differentiated on the market by offering higher performance, technology, function or quality (Ericsson & Erixon, 1999). The product leadership strategy entails that creative ideas should be able to be realized quickly, which is made possible by having fast and efficient business and management processes (Treacy & Wiersema, 1993). The companies pursuing the product leadership strategy usually have high development costs. In total, time to market becomes a critical factor for these companies’ success (Ericsson & Erixon, 1999).

2.3.2 Operational Excellence

Companies pursuing the operational excellence strategy aim to lead the industry in terms of price and convenience (Treacy & Wiersema, 1993). The aim is to do so by optimizing the business processes across the entire company, by using standardization and high productivity, having an even quality and low production costs (Treacy & Wiersema, 1993). One indicator for measuring complex direct and indirect costs is part number count, which is the total number of unique parts needed to manufacture all product configurations in the module platform (Niethammer, 2014). A high number of unique parts is an indication of complex manufacturing processes and higher direct and indirect cost (Niethammer, 2014).

2.3.3 Customer Intimacy

Companies pursuing the customer intimacy strategy aim to tailor the products to closely meet the customer's needs (Treacy & Wiersema, 1993). The critical factor is to establish high customer loyalty and the strategy usually means having lower product efficiency and higher indirect costs (Maylor, 2010). Eventually, even though the purpose of modularization is to
enable the company to pursue and be successful in all three product strategies, all companies must know what their main strategy is (Modular Management, 2012c).

2.4 Constraints

Despite the clear purpose of modularization, it is in practice very difficult to perform the perfect modularization (Yu, 2016). Companies operating in the commercial vehicles industry need to comply with certain technical restrictions and legal requirements, which are not always easy to foresee (Åkeson, 2017a). Above all, is that companies need to have a financially sustainable business, in order to survive.

The industry in which Scania operates mainly has three industry specific constraints: technical restrictions, legal requirements and commercial vehicle (Yu, 2016). Technical restrictions concern for example solid mechanics. Legal requirements sometimes vary depending on the market but may concern properties such as length, width and weight of the vehicle. There are also legal requirements on pollutant emissions and requirements that concern the safety of occupants and other road users. The commercial vehicle refers to the profitability of the products and that the products need to meet the customers’ requirements. These are all constraints that companies operating in the commercial vehicles industry need to comply with, even though there may be certain variations on the regulations requirements over the world.

2.5 Modularization Drivers

In order to determine what factors are affecting component modularization it is essential to first understand that there are different strategic drivers for applying modularization. There is not one specific modular product architecture that fits all companies (Borjesson & Hölttä-Otto, 2014). The architecture rather depends on the company’s strategic intents, which can be company specific, product specific or module specific (Ericsson & Erixon, 1999). The different strategic drivers for modularization cover the entire lifecycle of a product and can be linked to different functions within a company. The fact that the drivers cover the entire product lifecycle is a way to consider the needs and strategic intents of different stakeholders of the product (Lange & Imsdahl, 2014). The drivers are used to indicate what technical solutions, subsystems or components should form a separate module and can further be used to systematically evaluate the technical solutions of a product (Ericsson & Erixon, 1999). In other words, the strategic driver serves as an indication for the creation of interfaces. Table 1 gives an overview of the different drivers for modularization, and its corporate strategies. Thereafter follows a description of the strategic drivers for modularization based on the phases of the product lifecycle.
2.5.1 Research and Development

In the product development and design, engineers address both modules that will change over the lifetime of a platform, but also modules that will stay the same (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). The reason for this may vary, but can be for example changes in customer demand due to technological shifts. Thus, there are three main drivers during product development and design:

- carryover
- technology evolution
- planned product changes

A **carryover** is a reuse of parts, subsystems or technology over different generations within the product platform. The functions of carryover modules have to comply with the requirements of the company and customer. However, the carryover modules are not on their own the main reason for the customer to choose the product over another product. The **technology evolution** refers to changes within parts due to a change in customer demand or technology shift. It entails a strategic technological development that is driven by external forces, such as new electronics, software or materials. An example of a technology evolution module may be the diesel engines within trucks. The diesel engines face a possible shift towards electrical or hybrid engines driven by global trends such as climate, energy and resources (Rüger W. et al., 2014). **Planned product changes** refer to the changes of parts due to internal forces, such as a new launch of a product, to meet different customer requirements or decrease production costs (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014).

2.5.2 Production

The drivers regarding production aim to fulfill having an effective and efficient production process (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). These drivers are all connected to the operational excellence strategy:

- common unit
- process and/or organization
- separate testing
- strategic supplier
Common unit are parts that can be used for large shares of the entire product assortment. The difference to the carryover is that common unit only concerns large volumes in production, whereas carryover results in long lifetime for a module. Process and/or organization entails having an efficient production, where parts that demand the same production processes are moved to the same module. The separate testing implies a higher quality in a sense that different modules can be tested before they are assembled; an independent testing of functions within a product. The aim is an enhanced traceability of concerns, as well as a decrease in feedback time. Strategic supplier concerns making conscious decisions on whether to manufacture certain parts or sub modules in-house or to buy in from available suppliers.

2.5.3 Customer

Customers of today have more specific requirements that the products they purchase need to meet (Bullinger et al., 1995). A company’s product fleet must therefore result in the appropriate level of variance. To be able to introduce new variants in an effective manner, the aim is that the variation should concern as few areas of a product as possible (Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). Preferably, the variation should also be achieved as late as possible in the production of a product as this decreases lead times, inventory and lower the overall cost. The drivers for variance are:

- technical specification
- styling

Technical specification refers to isolating specification driven variance. An example given by Modular Management (2012b) is the architecture of certain laptop chargers. The wall sockets vary depending on country or region, as do the sockets of the laptop depending on model or generation. The voltage of the battery is another property that may vary. For this reason a modular architecture of a laptop charger can be to determine the cord and the plug to the wall socket to be one module, the transformer to be another module and the cord and the plug to the laptop socket to be a third module. The styling driver concerns changes in styling or design that are visible to the end customer, a brand-driven variance in appearance (Lange & Imsdahl, 2014). Certain areas of a product are more sensitive to new trends in terms of appearance.

2.5.4 Aftermarket

In the later stages of the product lifecycle, when the product has been released to the market, there are other strategic drivers (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014):

- service and maintenance
- upgrading
- recycling
Customers value that service and maintenance can be performed quickly. To help this, companies can create certain service modules containing parts that are more likely to be in need for service and maintenance. Upgrading means that the product lifetime can be prolonged or the product performance improved. The upgrading regards adding new functionality, rebuilding the product for another purpose or to enhance the product’s performance. With a larger environmental focus, the recycling is also an important driver for modularization. Customers of today demand sustainable solutions and the recycling of products can be enhanced by for example using less different materials in each module. Additionally, more easily recyclable material can be kept separate to facilitate the disassembling of products to recyclable and disposal material.

2.6 Incompatible Modularization Drivers

All drivers are not compatible with each other, which means that they do not support the same strategic intent. There is a conflict between carryover and technology evolution, as well as carryover and planned product change (Lange & Imsdahl, 2014; Modular Management, 2012b). This is since these drivers are different with regards to time. The strategic intent for a carryover module is to be sustainable and valid over several generations of a product, while the strategic intent for a technology evolution module is to be changeable when exposed to external forces such as shifts in technology. Similarly, the planned product change modules have the strategic intent of being changeable, as they carry certain features that may change due to for instance the launch of a product (Eastman, 2012). As argued by Modular Management (2012b) there is also a conflict between carryover and styling, which may refer to that styling can be affected by trends that change with time.

The driver common unit is not compatible with the drivers styling and technical specification (Lange & Imsdahl, 2014; Modular Management, 2012b). This is due to that the strategic intents of these drivers are different in terms of variance. When common unit refers to a reuse of components over large shares of the product assortment, styling refers to certain characteristics and variation to distinguish the product in some way and technical specification is directly related to handling of variation and customization effectively.

Lange and Imsdahl (2014) also argue that there is a conflict between technology evolution and process and/or organization. The technology evolution means that there will be a change of components due to external forces, whereas process and/or organization refers to create efficiency in production, for example by reusing certain manufacturing processes. The strategic drivers are in other words different in terms of change.

The primary implication of these incompatible drivers is that one module should not have conflicting strategic intents, in other words components with conflicting drivers should not be put in the same module (Ericsson & Erixon, 1999). There may be specific reasons for why components carrying conflicting strategies are put in the same module. However, this has to
be a conscious decision, where implications and consequences of this product structure are discussed within the company.

2.7 Methods for Modularization

The Modular Function Deployment (MFD), visualized in Figure 4, is a method for finding the optimal modular product design based on the company’s specific needs (Erixon, 1998). Regardless of industry the MFD can be used to connect the company's strategic objectives and the product architecture with the use of module drivers (Lange & Imsdahl, 2014). The method consists of five steps and involves the entire concept phase of the product development process, from the idea generation phase to finished product structure. The starting point can vary and a product development project may require iterations before the expected result is reached (Ericsson & Erixon, 1999).

![Figure 4. Modular Function Deployment](image)

A prerequisite to start a product development process is to have a well defined product strategy, including brand image (Ericsson & Erixon, 1999). The first step entails to define customer segments and customer values. The second step entails selecting technical solutions that fulfill the product properties. A technical solution is referred to as a physical unit designed to realize product properties and to generate a function for the product. Once the technical solutions have been selected it is possible to move on to step three in the MFD which implies creating module concepts. In the fourth step, the defined module concepts are evaluated against existing design. Implications in production efficiency, product development as well as product assortment are examples of what can be included in the evaluation. Step five implies formulating specifications for each module. The specifications include for instance technical information and descriptions of variants, and constitute the foundation for the product platform. Once each module is defined and specified, improvement of each module can continue separately.

We choose to present the third step of the MFD, generate module concepts, in detail as this step includes the usage of the different drivers for modularization. Furthermore, the generation of module concepts is highly relevant for the scope of this thesis, which aims to assure that modules have a clear strategic reason. Once the technical solutions have been selected it is possible to move on to the step in the MFD which involves creating module concepts. The Module Indication Matrix (MIM) enables identification of modules by
analyzing the relationship between the technical solutions and the module drivers (Erixon, 1996). The proposed modules developed in step two can be used as a starting point for developing a MIM to make sure that the modules make sense from a strategic point of view (Lange & Imsdahl, 2014). In the MIM, each technical solution is weighted against the module drivers on a scale where nine indicate a strong driver, three is considered a medium driver and one is a weak driver. Each module driver represents a parameter that in some way contributes to a strategic intent. In this way it is possible to create modules that match the initial strategic intention with the product. A highly weighted driver indicates that a technical solution should be kept alone and creates a module on its own. A module driver that is weighted low indicates that the technical solution should be combined with another technical solution and form the foundation of a module. The MIM can also show conflicts in strategies (Modular Management, 2012b). For instance, if a technical solution scores high in the common unit driver as well as in the technical specification driver there is a strategic conflict. Conflicting strategies is an indication that the technical solution should be divided into sub-technical solutions and connected through interfaces.

It is important to remember that the MFD should not be used to improve the design on a component level (Ericsson & Erixon, 1999). The MIM, however, can be utilized to understand the strategic intent each module serves. That understanding can be used as an indication for how a module and its components should be improved. For instance, if a module’s main strategic driver is to be a common unit then the module should have a design that is easy to produce in large volumes.
3. Scania’s Way of Working

In this chapter the purpose of modularization according to Scania as well as the Scania modularization principles is presented. Furthermore, methods particularly important for meeting the modularization principles and the product development process at Scania are introduced.

3.1 Purpose of Modularization According to Scania

Scania’s main purpose of applying a modular product architecture is to be able to offer a wide range of products to meet high variety in customer demand (Scania CV AB, 2011). More specifically this means to be able to realize shifts in customer demand as well as legal requirements as quickly as possible without loosing the control of the product platform. Furthermore, the purpose of modularization also concerns to enable the customer to pursue a lucrative business. One of the major challenges that come with modularity is to understand and incorporate the diversity in demand into a common modular product architecture. The strategic decision to exclusively offer trucks in the heavy truck segment plays a central part at Scania and having medium-duty trucks in the product assortment would require an entirely different modular system.

3.2 Scania’s Modularization Principles

Methods and processes vary a lot between different functions within Scania. Instead of having strict rules of how to apply the concept of modularization within each function, Scania has developed three modularization principles in order to create a shared and coherent way of thinking about modularization (Scania CV AB, 2011). The principles should constitute the fundamental mindset in the daily work, independent of function and with regard to modularization. All employers should understand both the opportunities as well as the challenges with modularization and the principles are minimum requirements that should never be overlooked.

The first modularization principle is to create standardized interfaces between series of components (Scania CV AB, 2011), where a series of components further on will be referred to as modules. Interfaces disclose how modules are interdependent and there are mainly three types of interfaces: contact interfaces, spatial interfaces and information interfaces. Contact interfaces describe transmission of power and load. Spatial interfaces are defined to make sure that components are not incorrectly in contact with each other. Informational interfaces define how components exchange data. Standardized interfaces imply that connections between components should be independent of module variants; meaning components with the same performance step should have the same interface. To be able to fully utilize the opportunities of having standardized interfaces it is important to clearly define the interfaces and to keep the standardized interfaces stable over time. Certain interactions may be easier to define than
others (Pimmler & Eppinger, 1994). For example, spatial interfaces are more easily defined than more uncertain conditions such as vibrations or heat. Keeping standardized interfaces stable over time is the most significant difference between a modularized product and a product build by technical platforms (Scania CV AB, 2011). Since the time aspect is central one need to continuously consider future demand in development projects. Standardized interfaces that are stable over time facilitate the continuous improvement of modules as one module may be developed independent adjacent modules.

The second modularization principle is balanced performance steps (Scania CV AB, 2011). This principle is a matter of understanding the customer and how the customer demand may change over time. The product architecture at Scania is called bygglårda, which is a toolkit containing information about all pieces required to create complete transport solutions. Balanced performance steps is a continuous trade-off. On the one hand the bygglårda should not contain more performance steps than what is required by the customer. If so, the bygglårda would be considered over modularized containing unnecessary and unwanted performance steps, and that would result in increased costs for the company. On the other hand, a balanced performance step implies a modular system containing modules enough to meet the needs of the customers. The bygglårda should also be balanced towards the competitors’ offerings.

The third modularization principle is same need, identical solution (Scania CV AB, 2011). If a customer does not have a requirement of a specific performance step Scania should, as far as possible, use an identical solution in terms of components. The purpose of this principle is not primarily to facilitate for the functions within Scania or to reduce costs but because of the customers’ similar need. One way to interpret this principle is to reuse the already existing components in the bygglårda.

3.3 Methods

Scania has three working methods that are particularly important in meeting the modularization principles (Scania CV AB, 2011). Operational factors and recommendations, is a useful method in the sales process. Variant-coded product structure facilitates the process of translating the user factors into a technical specification useable for R&D and Production. Finally, the variant part tracking (VPT) method is used during decision making for development projects. These methods exist to make sure that the customer's needs are central, and that the amount of parts does not increase uncontrollably.

At Scania, the modularization begins and ends with the customer. The first stage in delivering a truck to the customer is to understand the customer’s needs. This is done through operational factors and recommendations, of which purpose is to translate the customer’s usage of the truck into technical properties. The dealer and the customer define the customer’s usage by factors such as price, driving and climate among others. The communication
between the dealer and the customer is facilitated through visualizations and symbols of different driving conditions.

Unlike most of Scania’s competitors, which offer their products as predefined models, Scania use a variant-coded product structure, which holds all possible product configurations (Scania CV AB, 2011). The variant-coded product structure consists of several steps where the first step is to find a combination of performance steps suitable for the customer’s usage. The user factors are translated into variant codes. The variant codes are then translated into technical properties. The specified product needs to undergo a technical check to make sure the desired combination is valid. If there are any conflicts regarding the previously collected requirements, this is checked in this part of the variant-coded product structure. The variant codes are complemented continuously, which is natural as the demands from the customers need to be made more specific along the process (Yu, 2016). For example, if the customer requires a long driving range this has several implications, such as fuel tank, tiers, aerodynamics and engine performance. If the design of the end product is verified by the product structure, the specification reaches the later part of the structure, which contains information of physical parts (Yu, 2016). Data can now be used for cost calculations, weight calculations, creation of design environments for CAD etc. Eventually the specification reaches the step where purchasing of parts, logistics and the assembly of the product is determined.

The purpose of the VPT is to visualize what implications a specific project will have on a specific series of components or modules over time with regard to the amount of unique articles and the amount of possible variants (Scania CV AB, 2011). This method is mainly used as support in the decision making process for new projects. The x-axis represents the number of unique articles and the y-axis represents the number of possible variants, Figure 5. The aim is to have a low number of unique articles that can result in a large number of different variants. When implementing a new generation of products, two generations usually have to live in parallel, which explains the increase in parts, step one to two in Figure 5. After some time, parts from the older generation can be phased out, which explains step two to three. Moreover, this is an iterative process towards a more modularized architecture. The VPT should not be used as a method for measuring modularization as it is difficult to determine the exact number of common articles for different variants. The VPT shall rather be used as an indicator to what extent a new series of components is modularized.
3.4 The Product Development Process

The product development processes within Scania consists of four main areas: pre development, concept development, product development and product follow up (Yu, 2016). The Product Development Circle, see Figure 6, gives an overview of the product development within Scania, which is based on continuous flow and improvement.
The white arrow represents predevelopment and consists of the two phases research and advanced engineering (Yu, 2016). Within research the main focus is gaining new strategic knowledge and within advanced engineering this knowledge is developed by technology and applications.

The yellow arrow represents the concept development, where different needs are turned into solutions (Cederberg & Enarson, 2016). The needs can be directly based on the customer, or be based on strategic needs such as new technology or legal constraints. The concept development phase starts with finding market opportunity and consists of planning and conceptual design. During the yellow arrow different risks with the development project have to be identified and quantified.

The green arrow visualizes the product development phase (Cederberg & Enarson, 2016). This phase starts with configuration and all involved functions individually performs a risk analysis to consider the feasibility of the project. The green arrow also includes scheduling and allocation of resources. Furthermore, a project definition is specified, which is also updated and continuously during the project. Projects can be of different characters such as design online, which are smaller projects requiring less than 1000 man hours, half a million SEK and constitutes maximum three different R&D departments (Yu, 2016). Projects that consist of the ordinary product program are called A-orders. Other projects are special orders (S-orders), which consist of customer needs that cannot be fulfilled with the ordinary product program. Fit for use projects have the purpose of releasing service capacity at a dealer level, shorten the lead time from order to delivery and reduce cost for the adaptions.

The red arrow represents the product follow up where the areas considered are field quality, delivery stop, production, product change request and design adjustment (Yu, 2016). Field quality is referred to as requests based on the module’s performance on the field.
4. Methodology

This chapter contains a description of what research methods have been used. The first part states what research design the investigation has. Secondly, the different data collection methods are discussed followed by an evaluation of the quality of the desired data.

4.1 Research Design

This research has a case study design as it investigates a phenomenon in the real-life context. A case study relies on several sources of evidence (Karakaya, 2016). This case study has been conducted using observations, human word and documents as sources of data. The phenomenon, which we have investigated in this case study, is what implications a modular product architecture has as well as the strategic reasons for modularization at Scania.

The study has been conducted using an inductive approach, which entails that the empirical data is gathered based on an observed and identified problem (Blomkvist & Hallin, 2015). In an early stage of the project we received a reference group at Scania, with which we discussed our findings along the project. This made our work iterative, as we sometimes changed our course of action depending on the outcome of each reference meeting. Having a reference group was a way for us to assure that all stakeholders of the project was involved and would eventually receive adequate value from our work. However, all members of the reference group belonged to R&D, which naturally influenced the thesis’ course of action. Despite that members of the reference group had a holistic view of Scania's modular system, other departments within Scania might have stressed other aspects and perceptions of modularization. Subsequently, theoretical concepts regarding modularization have been used to make better understanding of the observed problem. The inductive approach allows a more exploratory course of action, unlike the deductive approach where the course of action is more of an explanatory character. With a deductive approach one should instead, from existing theory, develop a hypothesis to test through collected observations and eventually confirm or deny theory. This approach is more frequently used in natural science search (Karakaya, 2016). An exploratory purpose is well aligned with our choice of using an inductive approach, since the research approach of the thesis was determined after we gained a deeper understanding of the case Scania.

Thematically this study is oriented around two areas within modularization. The first area regards modular product architecture and the second area regards strategic reasons for modularization. RQ1 regards how Scania is applying the concept of modularization, more specifically the modular product architecture at Scania. RQ2 regards why Scania is applying the concept of modularization, namely the company’s strategic reasons for modularization during the different phases of a product lifecycle. RQ3 regards why Scania is applying the modularization on a module-specific level. The research process is visualized in Figure 7.
This case study has partly been conducted in collaboration with a third student where the interviews regarding RQ1 and RQ2 were held together with the third student. The reason for this was that we were interested in interviewing the same people. The interview guides were designed separately as we were aiming to understand modularization from slightly different angles. The third student focused on measuring modularization and these questions were held during the second part of each interview, which is why the reliability of this report should not have been affected negatively. We were also keen on that the questions made sense from the respondent’s point of view. When the interviews had been held the reports have been written independently and the empirical data gained by the third student has not been used in this report. The interview guide for RQ1 and RQ2 is to be found in Appendix A.

4.2 Data Collection

In this section we present the main methods, which have been used for gathering data. Empirical data has been collected through interviews and literature review. Both primary and secondary sources have been used.

4.2.1 Contextual Understanding

In an early phase of this research we held nine unstructured interviews with purpose of understanding the case Scania. This means that we had no prepared questions but rather let the respondent speak freely about his or hers subject and in relation to modularization. The choice of respondents was made in collaboration with our supervisor at Scania, based on area of expertise. A list of respondents is shown in Table 2. The list states the respondent's title, the topic of the interview and the date for the interview. All of the respondents work at the R&D department at Scania, which is natural since we aimed to study modularization in an R&D context.
Table 2. Conducted interviews for contextual understanding

<table>
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<th>Title</th>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Coordinator</td>
<td>2017-02-03</td>
<td>Introduction to the product architecture at Scania</td>
</tr>
<tr>
<td></td>
<td>2017-02-06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2017-02-07</td>
<td></td>
</tr>
<tr>
<td>Design Engineer</td>
<td>2017-02-06</td>
<td>Sharing Experiences of Modularization</td>
</tr>
<tr>
<td>Expert Engineer</td>
<td>2017-02-08</td>
<td>Introduction to Interfaces</td>
</tr>
<tr>
<td>Product Coordinator, Business Architect</td>
<td>2017-02-14</td>
<td>NCG - Modularization Measurement</td>
</tr>
<tr>
<td>Product Coordinator</td>
<td>2017-02-14</td>
<td>Product Description</td>
</tr>
<tr>
<td>Design Engineer</td>
<td>2017-02-17</td>
<td>Valve Installation Modularization</td>
</tr>
<tr>
<td>Senior Engineer, Product Structure Engineer</td>
<td>2017-02-17</td>
<td>Air Inlet Installation Modularization</td>
</tr>
</tbody>
</table>

The unstructured interviews enabled us to quickly get an understanding of the case Scania and how the company works with modularization. Furthermore, we gained a brief understanding of how the product architecture at Scania is structured and what the challenges are regarding modularization. We used the outcome from these interviews to set a focus for this master thesis.

4.2.2 Literature Review

When collecting data, it is critical to evaluate the existing knowledge of the research area (Blomkvist & Hallin, 2015). It is essential to carefully read up on what has already been done. This is to clarify how to continue to build on existing knowledge. The literature review that we conducted during this case study focuses on modular product architecture and strategic
drivers for modularization. The literature gathering was in the beginning rather broad and narrowed down during the research process. The purpose with the literature review was to gain an understanding of modularization and implications of modularization through secondary sources. The literature review also served as a foundation for the structure of our report, the interview guide and the thematic analysis. Moreover, we were able to position our own study in relation to previous research.

Search tools such as Google Scholar, KTH Primo, Scania Inline and Science Direct has been used to find books, scientific articles, journals and reports useful to build a theoretical platform. Main keywords when searching for literature within the research area are: “Modularization”; “Modular Function Deployment”; “Module”; “Modularity”; “Product Architecture”; “Drivers for Modularization”; “Corporate strategies”; “Powertrain”; “Functionality”; “Technical solution”; “Product platform”

4.2.3 Interviews

We have held two rounds of interviews. With the first round of interviews we aimed to answer RQ1 and RQ2. The interviews from the first round were held with individuals possessing responsibilities highly relevant for answering the questions how and why Scania is applying the concept of modularization. The second round of interviews enabled us to answer RQ3, which is formulated to answer the question why Scania is applying modularization on a module level, unlike RQ2 that regards the company-specific why.

**Developing interview guide**

When collecting empirical data, semi-structured interviews are by far the most common interview structure (Blomkvist & Hallin, 2015). This entails that the interview questions are oriented around specific themes or areas. The interview guides have in our case a similar structure as the theory and literature sections of the report; see Appendix A and Appendix B. To get to know the respondent and create a relaxed environment the interview guide starts with a set of introductory questions.

For the first round of interview then followed questions regarding the Scania specific case, namely the concept of modularization, a modular product architecture and questions related to the company-specific reason for applying modularization along the product lifecycle. After the semi-structure interview was completed, during the first round of interviews, we asked the respondent to fill in a ranking form, where the respondent had to rank the different strategic reasons for modularization based on relative importance. This we did as a complement to the qualitative questions. Quantifiable answers are comparable answers and are used to support the result from the qualitative questions (Collis & Hussey, 2013).

For the second round of interviews, the introduction questions were followed by questions regarding the powertrain, its modules and their functionality and strategic reason, see Appendix B. In addition to the semi-structured questions, the interview guide regarding RQ3
also contained some structured interview questions. This since we were aiming for more specific answers, as opposed to the first round of interviews.

The inductive approach of the case study is reflected particularly in the first round of interviews, as this interview guide was created iteratively. The first iteration of questions was created firstly based on secondary sources, namely the literature and theory. Before conducting the real interviews, we conducted a test interview with our supervisor at Scania, during which we took notes on suggestions on our own thoughts of improvement. Choosing our supervisor at Scania as a test respondent was reasonable since he has similar responsibilities and insight as the chosen respondents. After the test interview, we discussed the following feedback questions with our supervisor:

- Did you understand all the questions?
- Was any question outside your area of expertise?
- Was any question formulated in an incorrect way?
- Did you perceive any of the questions to be leading questions?

The purpose of the test interview was to be able to change or revise questions that were not formulated precisely enough and also get an indication of the time frame. Based on feedback from our supervisor as well as with deeper knowledge based on scientific literature and theory, we refined and revised the interview questions with the intention to gain more valuable answers to the research questions. We for instance developed the interview guide further to have a reasonable amount of questions in order to avoid question fatigue. This was especially important since we held our interviews in collaboration with a third student who also conducted his master thesis as Scania and within the same field, namely modularization.

We were also able to make sure that the questions were collectively exclusive. The improved interview guide increased the validity of the study. However, the interview guide could have been further developed if we were able to test the interview guide with more than one person.

The aim with the interviews, regarding the company specific reason for modularization as well as for the questions related the powertrain, was to receive the respondents’ initial thoughts on the topic. Therefore, we chose to not communicate the interview guide to the respondents in advance, as this would have increased the risk of receiving biased answers. This is since the respondent has got time to prepare answers and thus steer the interview in a certain direction. We were keen on to receive reality-based answers according to the Scania case. On the other hand, communicating the interview guide in advance can have a positive effect on the validity of the empirics; due to the fact that the respondent has got time to explore the questions further to give more comprehensive answers.

**Performing interviews**

All interviews were held face-to-face, in English and lasted between 50 and 90 minutes. We decided to record all interviews, in consultation with each respondent, to make them available
for us to use later, which increases reliability (Patel & Davidsson, 2003). However, when recording the interviews, it is important to consider that this can create an atmosphere where the respondent answers restrictively (Karakaya, 2016), thus a higher reliability is obtained at the expense of validity. After conducting each interview, we transcribed it and from that the result of this report is derived.

Some of the questions during the first round of interviews were very broad. We for instance asked the respondent to define concepts like modularization and modular product architecture. Answers to such questions can be ambiguous, and to make it more clear we asked clarifying questions such as, “What do you mean by that?” and “Could you give us an example?”. This method is referred to as using probes (Collis & Hussey, 2013).

The purpose of the first round of interviews was to answer RQ1 and RQ2 by gaining valuable insight from primary sources in order to understand the concept of modularization and how it is currently applied at Scania. For this reason, we chose to interview people from the R&D department at Scania but also two external experts on the topic modularization. By analyzing the area of research from multiple perspectives and triangulating the empirics we were able to establish validity of the results. We made a conscious decision to mostly interview people from the R&D department as we made the assessment that modularization at Scania is governed by the R&D department, since this is the department where decisions regarding development projects are made. This is supported by Ulrich (1993), who argues that the R&D department is particularly relevant because most of the decisions are made during the early phases of innovation or development.

A list of respondents from the first round of interviews, their title, department as well as the date for the interview is shown in Table 3. Each respondent has an acronym to facilitate the referencing to the specific respondent in the result and analysis section. All interviews, both the first and the second round, took place in Stockholm or Södertälje during spring 2017.
**Table 3. Conducted interviews for RQ1 and RQ2**

<table>
<thead>
<tr>
<th>Title</th>
<th>Date</th>
<th>Department</th>
<th>Acronym</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhD Student Modularization</td>
<td>2017-03-27</td>
<td>Product Description Methodology</td>
<td>PhD1</td>
</tr>
<tr>
<td>Founder &amp; CEO of Modularity Consultancy Firm</td>
<td>2017-03-28</td>
<td>External</td>
<td>C1</td>
</tr>
<tr>
<td>Docent in Machine Development</td>
<td>2017-03-28</td>
<td>External</td>
<td>D1</td>
</tr>
<tr>
<td>Senior Technical Advisor</td>
<td>2017-03-29</td>
<td>Truck, cab and bus chassis Development</td>
<td>R1</td>
</tr>
<tr>
<td>Head of Modularization</td>
<td>2017-03-29</td>
<td>Modularization</td>
<td>YD1</td>
</tr>
<tr>
<td>Consultant Uniter AB</td>
<td>2017-03-30</td>
<td>Technical Product Planning</td>
<td>C2</td>
</tr>
<tr>
<td>Head of Operational Performance</td>
<td>2017-04-03</td>
<td>Operational Performance</td>
<td>YD2</td>
</tr>
<tr>
<td>Chief Engineer</td>
<td>2017-04-03</td>
<td>Modularization</td>
<td>YD3</td>
</tr>
<tr>
<td>Business Architect</td>
<td>2017-04-04</td>
<td>Product Description Methodology</td>
<td>YM1</td>
</tr>
<tr>
<td>Engineer Director</td>
<td>2017-04-11</td>
<td>Technical product planning and vehicle validation</td>
<td>YD4</td>
</tr>
<tr>
<td>Expert Engineer</td>
<td>2017-05-05</td>
<td>Trucks layout &amp; concepts</td>
<td>RT1</td>
</tr>
</tbody>
</table>
For the interviews regarding RQ3, namely the conceptualized example of the powertrain, we chose to interview people both from R&D and sales & marketing at Scania. The interview questions to the respondents representing the R&D department were slightly different than the questions to sales & marketing department. With the R&D interviews we gained a more technical understanding of the powertrain and the functionality of each module. With sales & marketing interviews we gained an understanding about choices the customer is entitled to do related to the powertrain.

When interviewing the R&D department, we asked if the certain module is strongly, fairly or weakly influenced by a certain module driver, see Appendix B. If the respondent answered that a module is strongly influenced by a certain strategic reason we asked why and if the respondent could elaborate on that answer.

A list of all respondents from the second round of interviews, their title, departments and the date for the interviews is shown in Table 4. As for the first round of interviews, each respondent has an acronym to facilitate the referencing to the specific respondent in the result and analysis section. The acronyms starting with an R indicate that the respondent work within the R&D department and acronyms starting with KT indicate that the respondent belongs to the sales & marketing department.

<table>
<thead>
<tr>
<th>Title</th>
<th>Date</th>
<th>Department</th>
<th>Acronym</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineer</td>
<td>2017-04-12</td>
<td>Vehicle Layout &amp; Description: Product Structure</td>
<td>R2</td>
</tr>
<tr>
<td>Product Coordinator</td>
<td>2017-04-12</td>
<td>Vehicle Layout &amp; Description: Product Structure</td>
<td>R3</td>
</tr>
<tr>
<td>Senior Engineer</td>
<td>2017-04-27</td>
<td>Operational Presales &amp; Projects: Product Configuration</td>
<td>KT1</td>
</tr>
<tr>
<td>Product Planning Director</td>
<td>2017-05-03</td>
<td>Product Management, trucks: Product Planning</td>
<td>KT2</td>
</tr>
</tbody>
</table>

The amount of respondents during round two of interviews were limited. We interviewed two respondents representing R&D and two representing sales & marketing. This could have been extended. However, we want to emphasis that the classification of the powertrain itself was
We took ethical aspects set by the Swedish Research Council into account when conducting interviews. There are four principal requirements to take into consideration (Blomkvist & Hallin, 2015). The purpose with these four principles is to protect the interviewee by informing about the purpose of the study and by making sure that people involved agree to be interviewed or studied. It, furthermore, requires the gathered information to be handled confidentially, also that the collected information is used in line with the initial purpose.

**Method for analyzing the interviews**

We applied thematic analysis for both the first and the second round of interviews, where the areas of analysis are visualized in Figure 8. The first round of interviews was analyzed according to two areas: product architecture and strategic reasons for modularization during the different phases of a product lifecycle. The first area regards RQ1 and consists of the product architecture at Scania and what implications it has on product change, product variety, component standardization and product performance. The second area regards RQ2 and consists of strategic reasons for modularization along the product lifecycle, which is divided into four phases: Research & Development, Production, Customer and Aftermarket. The second round of interviews consists of one area and regards RQ3, which is strategic reasons for different modules. The analysis is then divided according to the modules forming the powertrain.

![Figure 8. The thematic analysis](image)

When analyzing answers from both the first and the second round of interviews, we have only presented key aspects. This means that we, for instance, have excluded some answers during
the second round even though we asked questions on all strategic reasons for all five modules forming the powertrain.

4.3 Quality of Analysis

Reliability and validity are necessary research concepts when gathering data and evaluating the quality of scientific work (Blomkvist & Hallin, 2015). In short, validity refers to studying the right thing that is if the study is able to scientifically answer the things it is intended to answer. Reliability refers to studying the right way that is if the study is performed correctly.

To reach high validity we have gathered literature firstly from prominent organizations and researchers. We have collected data from scientific articles that have been cited several times as this increases validity. Non-scientific literature has been used cautiously because of the risk of receiving biased information, which has negative impact on validity of the case study. However, non-scientific literature has been used as inspiration and also for triangulation with scientific literature and data gathered during interviews.

Critical for reaching high reliability is that the case study, as far as possible, is designed so someone else can perform it but still reaching the same results. However, in a social science case study, this is one quite complex task. This is due to the fact that the sources for research are based on human words, communication and observations (Karakaya, 2016). Reliability is often limited because of the nature of performing semi-structured interviews. However, reliability of the study is increased since the interviewing was performed in pairs. When one person was responsible for interviewing and the other was observing and taking notes this limited the risk for misinterpretation. Therefore, we chose to use this approach when performing interviews. Another aspect that increases reliability is recording during interviews to make them available to use later. However, we were aware that recording during the interview could have create an environment where the interviewee corresponds restrictively, thus validity of the empirics is affected negatively.
5. Product Architecture

This chapter regards RQ1 where different implications of a modular product architecture is presented and analyzed. First, we present and analyze the respondents’ view on a modular product architecture. Thereafter, we present and analyze the implications of modularization which concern the five areas: Product change, Product variety, Component standardization, Product performance and Product development management.

A modular product architecture is made of building blocks or modules, where a module is referred to as a physical realization of a specific function (D1, 2017; C1 2017). PhD1 (2017) argues in line with Ulrich (1993), that the decoupled interfaces between these modules is the main thing that defines a modular product architecture, allowing a change on one side of the interface without having to change the other side. Furthermore, a product property or function should be connected to one, and only one, physical component. A modern water tap is a good example, where the different functions, such as pressure and heat, are controlled independently. Creating an architecture where interfaces are decoupled is in reality a complex task. At manufacturing companies like Scania, there are usually a lot of dependencies between different modules and it is always a tradeoff between decoupled interfaces and the performance of the product. The opposite of a modular product architecture is an integral product architecture. In this case, multiple desired functions may be fulfilled through one single technical solution (PhD1, 2017).

It is clear that the interfaces have a central role when speaking about the modular product architecture at Scania, and YM1 (2017) even argues that the interfaces themselves define the modular product architecture. To be able to fully utilize a modular product architecture, the standardized interfaces need to be kept stable over time (YD2, 2017; D1 2017). It is clear when analyzing the respondents’ statements, that it is a challenging task to keep the interfaces stable over time since a truck is a complex product containing a lot of technology that is dependent and ever changing. The interfaces exist to protect the architecture, which is why they need to be controlled and documented and changes of interfaces need to be carefully evaluated. To be able to cope with this Scania has developed a specification of the different levels of interfaces, which are more or less difficult to change (RT1, 2017). Legal interfaces are determined based on legal restrictions and are not, under any circumstances, changeable. The next level of interfaces is the strategic interfaces, which are defined by Scania. These interfaces should be fixed for a long period of time and valid for current and coming performance steps. The ground clearance interface and the bodywork interface are two examples of strategic interfaces, which are there to facilitate the use and the performance of the truck. Changes to the strategic interfaces are made by cross functional teams including representatives from R&D, market, purchase and aftermarket department. Before a change is realized the team carefully evaluates what implications a possible change could imply from different perspectives. Project interfaces are valid for certain projects; it can be exceptions from a strategic interface.
The product architecture at Scania is called the *bygglåda*. It is a toolkit containing information about all pieces required to create complete transport solutions (YD1, 2017; YD2, 2017; YD3, 2017). Respondents at Scania argue that they do not develop trucks, but rather a *bygglåda* from which trucks can be created and configured from modules or components. The customer gets to combine performance steps to create the optimal product for its usage, and it is first when the components are assembled a vehicle is created. The use of the *bygglåda* is very different from how other truck manufacturers put together and offer their products. In comparison to the *bygglåda*, which contains no predefined configurations of performance steps, other manufacturers offer predefined variants with specific performance steps.

5.1 Product Change

A modular product architecture has certain implications on product change, and some respondents argue that a modular product architecture is in itself prepared for future product change. In line with Ulrich (1993), YD3 (2017) and PhD1 (2017) argue that a modular product architecture enables changes on a modular level. If the modular architecture is well defined and documented, changes on a modular level may be done without causing implications on, or interfering with, other modules. Changes on a module level are facilitated through the decoupled interfaces. First and foremost, the interfaces need to be robust and stable over time to facilitate product change, at least that is what three respondents argue (PhD1, 2017; YD2, 2017; YD4, 2017). C1 (2017) emphasizes that interfaces should not be kept stable over time per se, it is rather important that changes of interfaces are made based on conscious decisions. If the customer benefit is strong enough, according to the business case of a development project, the interfaces have to be changed otherwise the design will go obsolete. Changes to the interfaces should only be done if it is supported by customer needs (YD4, 2017). At Scania, something called Continuous Evolution of Properties Planned in Small Steps (CEPPSS) concept is used, which allows Scania to do small changes to the product continuously and in parallel (PhD1, 2017; R1, 2017; YM1, 2017). Again, this is enabled through the modular product architecture and the decoupled interfaces.

Unlike Ulrich (1993), D1 (2017) emphasizes that there is a time aspect to the product change. With a modular product architecture, some of the respondents argue that product change can be realized much quicker in comparison to product changes in an integral architecture. The decoupled interfaces enable separate testing of the module variants that are being changed, and this will save time and complexity (YD2, 2017). Changes to a product with an integral product architecture is different. A Formula 1 car most often has an integral product architecture, and even the smallest change might imply changes to the entire car. YD3 (2017) and YD4 (2017) however argue for the opposite, namely that product change in a modular product architecture is very time consuming. Scania needs to consider that the development of modules or components must fit all variants, for example from a four by two long haulage truck for Europe to a ten wheeler Indonesian mining truck (YD3, 2017). This means that
Scania rarely is the first to the market, nevertheless is the company the last one to release the latest introduction. Scania develops for variation from the start and only once for the entire bygglådan, unlike other companies using a platform based architecture.

PhD1 (2017) and YD2 (2017) claim that changes on a product level can be limited by the modular product architecture, which also is supported by Ulrich (1993). Scania is very flexible within the bygglåda but if the company would like to develop a completely different product, for instance an electrical vehicle or trucks targeting other segments than the heavy truck segment, it might require an entirely new bygglåda.

In addition to what Ulrich (1993) states, C1 (2017) claims that the modular product architecture can be vulnerable to disruptive technologies. There are a lot of examples of events that have impacted manufacturing companies through history. Sony for example had a large focus on developing the modular product architecture when developing the Discman and Walkman. This resulted in that the company missed new disruptive technologies that changed the customers’ needs completely, such as the mp3 technology. Keeping the modular product architecture and the interfaces for too long could naturally become a risk. This reasoning is closely linked to what YD1 (2017) argues, that with an integral product architecture it is easier to start developing a new product from the beginning and thereby adjust to new disruptive technologies. In addition, YD2 (2017) states that it is very difficult to know if Scania’s current product architecture, the bygglåda, is optimized for new purposes that may emerge from disruptive technology.

5.2 Product Variety

The majority of the respondents argue that one of the main implications of a modular product architecture is the ability to create product variety, which also is in line with Ulrich (1993). This is facilitated through configurability, where configurability is referred to as the ability to combine components, creating a large amount of solutions with different module variants (C1, 2017). The configurability is accomplished through the decoupled interfaces (YD1, 2017; R1, 2017). Configurability generates multiplicative effects and thereby a large variety while keeping control of the complexity and costs, which also is pointed out by Ulrich (1993) as a positive implication with having a modular product architecture. PhD1 (2017) has a similar view on product variety, namely that a modularized product architecture enables creation of external variety and internal commodity. This is done through the combination of the different module variants. A modular product architecture might not create the solution to meet what the customer is asking for to the exact millimeter. Modularity strives to get as close to the optimal solutions that anyone would ask for, and for reasonable costs.

There are constraints that limit product variety to some extent. Weight and strength restrictions are examples of constraints that limit the product configurability and thereby limit
the product variety (D1, 2017; R1, 2017). However, YD3 (2017) claims that Scania can create as much variance as wanted.

The bygglåda at Scania does not hold a description of a final truck but variant codes that can be combined into a complete vehicle (R1, 2017; YD4, 2017). This allows Scania to customize the truck for its usage at a reasonable cost. Competitors working with predefined models only offer finished solutions that can imply trade-offs on user factors or desired features. YD3 (2017) argues that the modular product architecture and the implication that allows product variety is a conscious decision made by Scania. The modular system encourages variation and variation is what generates the company's revenue. A standardized product architecture, on the other hand, inhibits variation. Looking at a Scania truck and a MAN truck you cannot tell that one is modularized and one is not, but looking at the entire fleet one can observe the interfaces are standardized for all Scania trucks in comparison to the MAN truck, which has varying interfaces. This has implications on a company’s ability to offer product variety.

While configurability is the strength with modularization, it is also a concern for Scania (YM1, 2017; YD3, 2017). The configurability places high demands on the sales department and distributors, which need to know the product thoroughly in order to reflect the different configurability options. There is a fine line between guiding the configurability towards appropriate options and keeping the fine tuning, which can be fulfilled with a modular product architecture. This is a difference to an integral architecture where the company has a smaller set of options. The size of the bygglåda is central, where Scania has to remove performance steps that are no longer used (YD4, 2017). It is also a question of information sharing, where the sales department needs to be fully aware of new solutions developed by R&D.

5.3 Component Standardization

Standardization on component and product level are not to be confused with each other. Modularization and standardization on product level are each other’s opposites, according to PhD1 (2017). Furthermore, that modularization normally has a top-down approach while product standardization has a bottom-up approach. With a modular approach you divide the product into different modules by looking at the entire system. With product standardization you often start by looking at the components.

C1 (2017) and D1 (2017) emphasize that it is very dangerous to start with component standardization, when having a modular product architecture. A good modular product architecture starts with understanding the customer need and develop the architecture based on that. Component standardization is secondary, as starting with component standardization would limit the offering in the end. If applying component standardization, it is important to remember that a manufacturing company often tries to differentiate itself and its products through what the customer can see, feel, smell and touch (C1, 2017). For that reason should
component standardization only be applied to modules or components that are not directly visible to the customer.

Scania has a modularization principle called “same need identical solution”, which can be interpreted as component standardization. This principle refers to the reuse of components in places of the truck that require the same need. Screws and wheels are examples of standardized components. YD3 (2017) even argues that two solutions for the same need is against the modularization principles. The respondents however do not claim that the Scania modularization principle “same need, identical solution” primarily is about creating efficiency in production and reduce costs, something that Ulrich (1993) brings up as a main positive implication of a modular product architecture and component standardization.

5.4 Product Performance

Ulrich (1993) defines product performance as how well the product fulfills the desired functionality. D1 (2017) claims that product performance is difficult to define, that it can refer to many different things such as, acceleration, weight per length, how much cargo a truck can take, price, cost for maintenance, and availability.

Ulrich (1993) separates global product performance and local product performance and most of the respondents are only reflecting on what could be derived to global product performance. PhD1 (2017) and C1 (2017) argue that a modular product architecture often results in more robust and heavy products in comparison to products developed from an integral product architecture. The solutions developed from a modular architecture are therefore not optimized for each product configuration. PhD1 (2017) even argues that modularity results in lower product performance in comparison to other product architectures. C1 (2017) argues that it is a challenging task to optimize on weight when having a modularized product architecture and that modularity may imply over dimension of components to fit the broader spectrum. This is also aligned with Ulrich (1993).

The principle that aims to have well balanced performance steps in the hygglåda could be interpreted to be related to product performance. If the performance steps are well balanced to fulfill the needs of the customer the performance should be right (YD4, 2017). D1 (2017) and PhD1 (2017) however state that product superiority at Scania may be held back by modularization. In many cases, it is not the performance from one component that is important but rather the performance from many performance steps combined. This is in literature referred to as global product performance (Ulrich 1993). It is therefore important to have the complete vehicle perspective when developing the product (YD4, 2017). This statement conflicts with Ulrich (1993), which claims that it is not possible to control the global product performance when having a modular product architecture. This is most evident when engineering performance has to be very good and product specifications are very strict, such as if the product has to be extremely light weighted. This is usually not a large concern.
in the heavy truck industry, in which Scania is operating. YD3 (2017) does not believe that Scania can excel in performance with a modular system, but rather reach similar product performance as competitors but in a more efficient way. Nevertheless, YD1 (2017) remarks that modularization inhibits Scania’s ability to build lighter trucks, for instance below 18 tons.

5.5 Product Development Management

Assuming that the product development process consists of four phases, the product architecture has implications on the three last phases (Ulrich 1993). These four phases are called concept development, system level design, detail design and product test and refinement. Looking at Scania’s product development process, it is built up in a somewhat different way.

The yellow arrow in Scania’s product development process is similar to the concept development phase mentioned by Ulrich (1993). This phase is equally handled no matter of what product architecture a manufacturing firm chose to apply. In other words, there are no implications related to product architecture to speak of in this phase.

Both the system level design phase and the detailed design phase, determined by Ulrich (1993), is represented in the green arrow of Scania’s product development process. The green arrow includes function analysis, configuration and product definition, which is comparable to what Ulrich (1993) describes as the system level design phase. Furthermore, the green arrow represents the scheduling and allocation of resources needed to realize a development project, this is equating with the third phase which Ulrich (1993) call the detailed design phase. To summarize, both the system level design phase as well as the detailed design phase is covered by Scania’s green arrow. The literature claims that, when having a modular product architecture one needs to put emphasis on the system level design, which implies development of the product architecture itself, while the detail design phase does not demand as much emphasis as if the firm would apply an integral architecture. This places high demand on Scania to know where the company should allocate the resources during the development process. This is also supported by the respondents, who claim that it is crucial to clearly define the interfaces.

The red arrow represents the product follow up phase in Scania’s development process. One may equate this phase with the product test and refinement phase which Ulrich (1993) mention. This phase is facilitated through a modular product architecture, provided that the modular system is clearly defined and holds decoupled interfaces.
6. Strategic Reasons for Modularization

This chapter regards RQ2, which concerns the corporate strategy for applying modularization at Scania and what the strategic reasons for applying modularization along the lifecycle phases are. The empirical data from the first round of interviews is presented and analyzed. What is called strategic drivers according to literature will further on be referred to as strategic reasons, as they concern something that should be achieved by applying modularization.

The most important corporate strategy for Scania to apply modularization is to offer the appropriate variation to meet the high and varying customer needs. This is what is referred to as applying a customer intimacy strategy (Treacy & Wiersema, 1993). Scania is able to create high variation through configurability, which enables the company to mass produce and customize the product simultaneously. C1 (2017) emphasizes that the main strategic reason for applying modularization is to fulfill customer needs but as well create economy of scale. Economy of scale is directly related to the corporate strategy operational excellence. Seven out of eleven respondents however argue that creating economy of scale is only secondary to the main corporate strategy of meeting a high variety in customer needs.

The majority states that the modularization at Scania starts and ends with the customer and the main strategic reason for modularization is to fulfill customer needs and to make the customer profitable. Even though the general purpose of modularization is to enable companies to be successful within all three corporate strategies, companies must know what their main company specific strategy for modularization is. The fact that Scania sees the customer intimacy strategy as their main focus, is consequently aligned with what is proposed by Modular Management (2012b). The result is further supported by the quantitative questions that regard a relative ranking of the strategic reasons for modularization. The quantitative questions were asked during the interviews, see Appendix A, and the result of these is presented in Appendix C. Worth mentioning is that the corporate strategy product leadership received the highest average ranking value. This is not in line with the respondents’ statements of customer intimacy to be the main strategy for modularization. However, the styling strategic reason stands out as the second lowest ranking, which has a negative effect on the average value for the customer intimacy strategy. It seems that the respondents do not see styling as an important strategic driver for modularization, which may be connected to the type of products Scania is developing. With this in mind, we still argue that the main corporate strategy at Scania is customer intimacy.

Despite the conclusion that the company specific strategy at Scania is to create customer value, the strategic reasons for modularization can still differ between the phases within the lifetime of a product. These are visualized in Figure 9, and will further be presented in the following sections.
6.1 Research and Development

Research and development (R&D) plays a central role regarding Scania’s company specific strategy of meeting a high variety in customer needs. The respondents discuss that one strategic reason for applying modularization during R&D is to be able to conduct concurrent engineering i.e. to develop different modules in parallel. Three out of eleven respondents highlight that when standardized interfaces are kept stable over time, multiple teams can develop different modules without hindering each other’s work. The independency of interfaces implies that the modules can be developed, maintained, tested and verified without having an impact on the rest of the product (D1, 2017). The respondents’ explanations of concurrent engineering as a strategic reason is similar to what is formulated as planned product change and separate testing (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). However, the ability to test module variants in separate before assembled, is according to literature primarily a strategic reason for production. Scania has a strong focus on R&D activities, and testing is always a part of the product development phase where both digital simulations and physical tests are performed. It is therefore reasonable to argue that the strategic reason separate testing may apply also in the earlier phases of the product lifecycle.

Several respondents discuss the time aspect, such as that a shorter time to market is a strategic reason for applying modularization during R&D. Three respondents argue that the modular architecture enables that Scania can meet new needs of the customer in relatively short time using a relatively small effort. Furthermore, a shorter time to market has positive effect on the total cost for R&D (YD2, 2017; R1, 2017). However, time to market and costs are of a different character compared to the other strategic reasons given by the respondents. Where planned product changes and separate testing are strategic reasons for R&D, a reduced time to market and reduced development costs may be seen as a result of these. As highlighted by R1 (2017) Scania’s main corporate strategy of creating a large variation to serve different customer needs is more important than both the impact on time to market as well as the positive effects on development costs.

Another strategic reason for applying modularization during R&D is an efficient use of resources. What respondents explain as an efficient use of resources may be broken down into...
the strategic drivers common unit, carryover and technology evolution. According to Ericsson and Erixon (1999) both common unit and carryover are strategic reasons connected to production, but the majority of respondents give arguments for why these are strategic drivers also during R&D. With a lower amount of part numbers, parts can more easily be accessed in the modular system (C2, 2017). YD4 (2017) furthermore argues that the reusing of parts over large shares of the product assortment means a smaller effort to understand how different components can fulfill different customer needs. In total this adds up to that development projects can be made using lean work, without unnecessary use of resources (YD1, 2017).

R&D also benefits from having the strategic reason of reusing modules over several generations. PhD1 (2017) gives the example of reusing different kinds of design work, such as cad models, calculations and testing. However, YD3 (2017) does not agree that the reuse of design is a strategic reason on its own, but rather emphasize that Scania should never have to design for the same purpose repeatedly.

Emphasized by Modular Management (2012b) is also that a strategic reason for R&D is to be prepared for change driven by external forces, such as new technology. This change is not in the control of Scania, but the company rather has to create the interfaces based on forecast of what is likely to change. This is however something that not all respondents explicitly state. YD2 (2017) remarks that it is very difficult to know if Scania’s current product architecture, the bygglåda, is optimized for new purposes, which may emerge from disruptive technology. Three respondents state that the main inhibition of pursuing modularization during R&D, is that the modular architecture needs to be maintained over time. This reasoning is in line with that technology evolution is a strategic reason for modularization during R&D, even though it is very complex to comply with this strategic reason.

6.2 Production

The respondents give a various amount of strategic reasons for modularization, regarding the production process. In accordance to literature a strong majority of the respondents clarify that having modules that are commonly used for large shares of the product assortment is the main strategic reason for the manufacturing. C1 (2017) also state that combining modules that run in high volume with modules that live over several generations, is good from a production point of view. These two strategic reasons refer to what is explained as common unit and carryover (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). At the same topic, one respondent argues that a lower amount of part numbers means that manufacturing will be more cost-efficient. Education of employees in production can be performed using less resources and investment of tools does not have to be unnecessarily large. In similarity to time to market regarding R&D, it is reasonable to argue that cost-efficiency is rather a result of several strategic reasons, and not a strategic reason in itself.
Three respondents highlight that by using resources more efficiently Scania can produce different variants without unnecessary deviations of the production line and carry a lower amount of stock. Despite creating unique end products, the assembly can be more or less standardized (YM1, 2017; YD1, 2017). YD4 (2017) and D1 (2017) emphasize that configurability is important during production as modularization enables the decision regarding the composition of module variants can be decided later in the process. Standardized interfaces may allow pre-assembling of module variants, where the desired module variant can be pulled to the production line when needed (C1, 2017; D1, 2017). This however requires a well-designed system to ensure that different module variants are assembled to the intended truck at the right occasion. Scania therefore has to keep and develop the module system in-house (YD1, 2017). By doing this the efficiency of the production line can be improved dramatically as you have shorter assembling in the final line (PhD1, 2017). To conclude the configurability should not be characterized as a strategic reason for modularization during production, but rather a means to reach the strategic reason of having a well-functioning production. This strategic reason is in literature called process and/or organization and entails having an efficient production, where for instance parts that demand the same production processes are moved to the same module (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014).

Regarding purchasing of parts, modularization enables economy of scale, but not at the expense of configurability. Three respondents argue that the main intent when buying in parts is larger volumes per part. Besides achieving economy of scale, the lower amount of parts means higher quality in production. Modularization allows the company as well as suppliers to build on existing knowledge, when developing already existing components (YD4, 2017). According to Ericsson and Erixon (1999) a strategic reason for modularization during production is that certain modules can be outsourced to suppliers that carry the appropriate expertise. Regardless, there are certain risks with modularization during production activities. C1 (2017) gives an example stating that if the strategic reason for a specific module is to provide superior performance or differentiation to the customer, this requires a conscious decision from the company. Superior performance modules or differentiation modules require a certain agreement with the supplier or a manufacturing in-house. If differentiation or superiority is passed on to competitors, the module’s initial intention to provide superior performance risk being turned into commodity. Scania has identified some components to be strategic modules and other components to be core modules (YM1, 2017). Based on that the company applies different requirements on the suppliers. If a module is core, Scania supplies the module itself but if a module is strategic the company has one or two premium suppliers. Even though a strategic reason is to outsource certain manufacturing of components to appropriate suppliers this requires clear boundaries on interfaces (D1, 2017). Furthermore, PhD1 (2017) states that a drawback with modularization is that the architecture will depend on what modules are available at the suppliers. It is not self-evident that Scania and the supplier share the same view on modularization and the structure of a module. Again, the
implications are that Scania has to give the suppliers very clear boundaries regarding contact, spatial and informational interfaces.

There is a misalignment between literature and the result received from the respondents, where literature state that separate testing is a strategic reason for production. The reason for this may be that all respondents are employees within R&D and may therefore give biased answers based on R&D’s perspective. On the other hand, Scania conducts extensive testing during specific stages of development projects, which is a possible reason to why respondents bring up separate testing only for the R&D phase. Two respondents argue that there are no direct strategic reasons for applying modularization during production at all, but the benefits for production is only a result of the strategic reasons for R&D. A reasoning that is not in line with literature.

6.3 Customer

A unanimous statement given by the respondents is that the main strategic reason for applying modularization regarding the customer is having the means of meeting specific needs. By utilizing a modular product architecture Scania is able to come very close to the optimal vehicle for the customer and provide the best value and profitability, for the price that the customer is willing to pay (YD1, 2017; PhD1, 2017). This is accomplished with configurability as a means and locating specification driven variance to certain modules. This reasoning is equal to what is called technical specification (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014).

YD4 (2017) argues that a strategic reason for applying modularization regarding the customer is being able to maintain high quality by having less number of part numbers. However, a lower number of part numbers does not result in a high quality per se. By having less number of part numbers Scania can have larger control of each part, and through the means of configurability the possibility to sell the appropriate solutions to the customer increases. YD4 (2017) further discusses that a lack of quality if a component breaks down can be based on either a pure quality issue or an issue of not selling the appropriate solution for the intended purpose. This enlightens the concern of transferring the customer needs into quantifiable performance steps. Nevertheless, connecting the less number of unique parts to the strategic reason common unit, this is primarily a strategic reason for production to achieve cost-efficiency. Having common unit as a strategic reason regarding the customer may come with risks such as that that component standardization becomes prior to the variation.

Besides being able to create the appropriate performance steps C1 (2017) mentions styling as a strategic reason for modularization. By creating styling modules companies can differentiate themselves and create a unique brand. However, styling is not mentioned to be a strategic reason by any of the internal respondents within Scania. There are several potential reasons for this, starting with that all respondents are employees within R&D. Working within R&D
does not necessarily mean working closely to the customer and knowing all preferences of the customer. Also, styling as a strategic reason may fit more or less with different areas within the truck. For instance, modules that are directly visible to the customer, such as the interior and exterior of the cab are more connected to styling. It seems however, that most of Scania’s physical components do not have styling as a primary strategic reason.

YD2 (2017) and D1 (2017) emphasize the time aspect, that Scania through modularization is able to quickly realize new solutions to meet customer needs. At the same time, it can be difficult to meet larger changes in customer needs in a fairly short period of time, due to the aspect of wanting to maintain the modular system over time. This is supported by YD1 (2017) who argues that competitors may be faster regarding developing new products optimized for a certain need. For disruptive performance steps, Scania may have a longer time to market. Modularization may be a drawback if customers do not accept the longer lead times (YD3, 2017; D1 2017). In similar reasoning to time to market for the R&D phase, the character of time to market is rather a result of others strategic drivers, and not a strategic reason for modularization on its own.

6.4 Aftermarket

All respondents state that modular product architecture means that service and maintenance can be performed more easily compared to an integral architecture. A strategic reason for applying modularization at Scania during aftermarket is therefore service and maintenance. This is partly due to that the reduced amount of part numbers enhances the possibility to keep parts on the shelf. It is also due to that technicians are familiar with the disassembling and assembling processes and fewer tools are needed in the emergency vehicle (YD3, 2017). The aim is that the newest part will replace the older spare parts, something that can be achieved only if the form and function of the part and interface is kept stable (YM1, 2017). If the bygglåda is kept up to date, Scania can reduce the part numbers and improve new parts, which results in that a better solution can be provided to the customer (YD4, 2017).

Besides service and maintenance, upgrading of module variants is facilitated through standardized interfaces as the modular architecture enables a reuse and reconfiguration of module variants (C1, 2017; PhD1, 2017). Eventually, C1 (2017) proposes that the recyclability can be a strategic reason for modularization and the aftermarket, as the company can chose to group certain materials into specific modules.

To conclude, the main strategic reason for modularization regarding after market is service and maintenance. Upgrading and recyclability are only mentioned by the external respondents. Therefore, there is a misalignment between the internal respondents’ perception and literature regarding the strategic reasons during aftermarket.
7. Strategic Reasons of Different Modules

This chapter regards RQ3, which concerns strategic reasons for different modules. A conceptualized example of the powertrain and its modules is also included in this chapter, where the modules are classified with regard to the strategic reasons for modularization. The empirical data from the second round of interviews is presented and analyzed.

Respondents C1 (2017) and C2 (2017) argue that modularization is rather strategic. Modularization is about the creation of customer benefits through, for instance, configurability. To create this, it is necessary to determine each module’s strategic reason. Similarly, Ericsson and Erixon (1999) state that each module in the architecture has its own strategic reason and that the different modules are of different character. Furthermore, that there are twelve strategic reasons for applying modularization. These strategic reasons are derived from the three corporate strategies that a firm can have: customer intimacy, operational excellence or product leadership.

We would like to present a conceptualized example of how different modules could be classified with regard to strategic reasons. The conceptualized example of classifying modules could function as a basis for decision-making during product development projects. The classification of different modules is derived from both the strategic reasons for modularization as well as the definitions of a modular product architecture and its implications.

We have, in a simplified manner, demonstrated an example on the powertrain of how a classification of modules can be applied. By breaking up the powertrain of a truck into five modules, and by interviewing people from both R&D and sales & marketing we were able to determine the main strategic reason for each module.

7.1 The Powertrain Case

We have divided the powertrain into five modules: engine, clutch, gearbox, propeller shaft and axle gear. This is also aligned with the actual product architecture at Scania (R2, 2017; R3, 2017). An overview of the entire powertrain is visualized in Figure 10. The colors in the figure visualize the breakdown of modules, made by us. In this section we will present the result from interviews regarding the powertrain, its modules, functionality and strategic reason for each module.
7.1.1 Engine

Seeing the engine as a module, its main functionality of the engine is to convert from chemical energy to mechanical energy (R3, 2017). The strategic reasons for the engine being a module are visualized in Figure 11.

<table>
<thead>
<tr>
<th>Engine</th>
<th>Strategic Reason</th>
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<td>Technology Evolution</td>
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<td>Planned Product Changes</td>
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<td>Separate Testing</td>
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<td>Technical Specification</td>
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<td>Pricing</td>
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<td>Styling</td>
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Figure 11. Strategic reasons for engine module

Scania is currently in a position when a new engine is to be introduced in cooperation with MAN (R3, 2017). This implies that the design of the engine but also the truck as a whole will be reviewed and changes will be made. As the engine is a module that Scania intends to develop and change as a part of the cooperation with MAN, this indicates that the engine could be classified to be a planned product change module.

Looking at a larger perspective, the engine is a module that is currently being exposed to external forces due to a shift in technology such as the electrification of engines. This suggests that the engine should also be classified to be a technology evolution module. The implications of the electrification of engines are that certain components will be removed and others will be added. It is important to pay attention to that changes in the engine module will impact the entire truck and result in changes within other modules. Thus the classification of the engine to be a technology evolution module is key in order to enable a smooth change.

The engine is manufactured at Scania and the design of the module results in a convenient assembly and installation in production (R3, 2017). The engine is further a module that is
exposed to a lot of testing before mounted to the chassis. Therefore the engine should also be classified to be a separate testing module. Furthermore, the engine is not particularly affected by styling as it is not visible to the end customer (R3, 2017). However, certain styling attributes may matter, for instance a shiny engine may give the impression that the engine is powerful. This implies that the engine could also be classified to be a styling module. The reason for this is not crucial, but in general styling is compatible with all other strategic reason mentioned regarding the engine.

There are several customer choices that are directly related to the engine (R3, 2017). The customer makes decisions for instance regarding the emission and the engine power (KT2, 2017). The customer is also entitled to choose the type of fuel. As there are a lot of direct customer choices regarding the engine, this module should be classified to be a technical specification module. Naturally, different choices have different constraints, something that KT1 (2017) describes as consequences of change. For instance, if the customer chooses ethanol as fuel type this implies certain restrictions on volume of the fuel tank, the type of cab and the type of gearbox. For this particular example the customer is not allowed to use the 13 liter tank, but only the 9 liter tank and the gearbox can only be automatic and not manual. Both engine power and fuel type are customer choices that are directly related to the customer application (KT2, 2017), which can be for instance general cargo, airport deicing, shipping container transport or livestock transport (KT1, 2017).

Half of the respondents state that the same engine can be used in different products within the product fleet. The same engine can be used in a small truck as in a large truck (R3, 2017). Nevertheless, both KT1 (2017) and R3 (2017) mention that the customer choices regarding the engine means consequences in other modules of the truck. Despite that the same engine may be used for a large share of the product assortment, the primary strategic reason of the engine should not be common unit. It is of certain importance to know that the strategic reason of the engine is technical specification and not common unit as these two drivers are not compatible with each other (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). The two reasons have completely different purposes regarding variance, where common unit refers to reusing components over large shares of the product assortment and technical specification is related to handling of variation and customization effectively.

In addition to having appropriate performance steps, or module variants, with regard to the customer’s technical need, the choices related to the engine is a matter of the customer’s price preferences (KT2, 2017). The performance steps are therefore crucial to Scania’s pricing. Sales & marketing needs entry performance steps, in order to sell the higher performance steps. For instance, the nine liter engines come in three different performance steps, where the lowest performance step exists only to serve the strategic need of selling the next performance step to the best possible pricing. Not all performance steps exist to serve technical needs, but rather to serve the commercial need. In literature, there are no strategic reasons that are
directly connected to the pricing of different modules or module variants. As Scania needs to be profitable, the pricing of products is important. It may therefore be worth to consider to add pricing as strategic reason. However, attention must be paid to that the strategic reason pricing only regards certain module variants, and not modules. According to the reasoning of the respondents there are no indication that entire modules exist to have pricing as only strategic reason.

The engine as such does not have a primary strategic reason to be easy to conduct service on (R3, 2017). However, KT1 (2017) reasons that the truck as a product needs to be serviced and maintained continuously but there is no specific module that is in more or less need of service. At Scania, the aim is to have an individual service planning, depending on the application of the truck. This is since different trucks have different needs on service. For instance, a long haulage truck does not need as much (or the same) service as a tipper used in the mining industry. It seems that what could be a service module in one product segment does not have to be a service module in another product segment. This highlights the question regarding if strategic reasons are not only module specific, but also product segment specific. R2 (2017) further states that even though it is important to be able to conduct service on the engine, it is rather sub modules within the engine that need to be easy to service and maintain. Therefore, the placing of the sub modules of the engine, such as the oil filter, is important. When determining strategic reasons, the classification naturally varies depending on the level of detail of the modules within the product structure. There is of course a trade-off between the level of detail and the simplicity of the result.

At rare occasions, the customer wishes to upgrade the engine (KT2, 2017), but it depends on the market. Outside Europe it is more common that trucks are sold from stock, which means that it is more common that there are upgrades of a truck. This is since upgrading is more time efficient for the customer compared to ordering an entirely new truck. Within Europe trucks are to a larger extent sold in consultation with the customer, which means less upgrades as the customer has good experience of the truck application. R3 (2017) supports this by arguing that the primary strategic reason for the engine is not to be easy to upgrade. As the upgrading varies a lot depending on different markets, this points to that the engine should not be classified to be an upgrading module in this conceptualized example.

7.1.2 Clutch

The main functionality of the clutch is to transmit the torque from the engine to the gearbox (R2, 2017). The clutch also transforms the uneven motion generated by the engine to a smooth motion that is transferred to the gearbox. The strategic reasons for the clutch being a module are visualized in Figure 12.
The clutch is a module that is used over different generations of trucks both in the current generation of trucks to the new generation of trucks (R2, 2017). The clutch has been and will be kept over time as it fulfills its purpose of transmitting torque and it is therefore no reason for Scania to change its design. This suggests that the clutch is a *carryover module*. However, with an introduction of electrical vehicles the clutch is sometimes completely removed since there is no need for it. When the engine is a typical technology evolution module, as it is its function of generating mechanical energy that is likely to change, a change or removal of the clutch is rather a consequence of this. This is why the clutch is not classified to be a technology evolution module.

The clutch generally has a similar physical form in all truck variants, even though the springs or covers may vary (R2, 2017). These are indications pointing towards that the clutch is a *common unit module*. That the clutch is also a carryover module is good from a production point of view, as it is a module that runs in high volumes but also lives over several generations. It is not affected by styling as it is not at all visible to the customer, which is good as carryover and styling, as well as common unit and styling, are not compatible.

Scania creates the design of the clutch module but does not manufacture any clutches in-house. The strategic reason for buying in the clutches is that the suppliers are experts in manufacturing clutches. If Scania would instead manufacture the clutches in-house this would require a large investment. The clutch should be classified to be a *strategic supplier module*. As Scania creates the design of the clutch the company can define the interfaces to follow its own modular product architecture. It is key that the interfaces are clearly communicated to the manufacturing suppliers, so that the modular product architecture does not risk to change unnecessarily. As the clutch is bought in by suppliers Scania does not perform any separate testing on this module. The clutch is rather tested when installed in complete vehicles, as it is a module that requires an engine and a gearbox to be able to test its performance. This is not enough to classify the clutch to be a separate testing module.

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<tr>
<th>Clutch</th>
<th>Strategic Reason</th>
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<td></td>
<td>Carryover</td>
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<td></td>
<td>Common Unit</td>
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<td>Strategic Supplier</td>
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**Figure 12. Strategic reasons for clutch module**
The customer does not make any direct decisions regarding the clutch (KT2, 2017). The choice of clutch is a result of other choices, such as choice of engine. Different engines have varying impact on the clutch, where one type of engine demands that the clutch is capable of handling large and uneven torque generated from the engine, whereas other engine types transmit a more even torque to the clutch, thus “requiring less” from the clutch (R2, 2017). KT1 (2017) further supports this by stating that there are no direct customer choices regarding the clutch but adds that the clutch is a consequence of the choice of gearbox. Once the type of gearbox is chosen there are certain decisions, which can be made by the customer. For instance, the customer can choose to have clutch wear protection if having the manual gearbox. All in all, the clutch should not be classified to be a technical specification module.

Even though the service aspect is not the primary strategic reason for the clutch to be a module, the modular architecture definitely facilitates a demounting of the clutch (R2, 2017). In similar reasoning to the clutch, the clutch could be a service module depending on its application. Depending on the application or usage of the truck, the lifetime of the clutch varies (KT2, 2017) resulting in more or less needs of easy service. It is not common for the customer to upgrade the clutch, even though it may be possible. Eventually, the recyclability is not a strong strategic reason for the clutch module.

7.1.3 Gearbox

The primary function of a gearbox is to convert speed and torque from the engine to other devices within the truck, something that is accomplished through gears and gear trains (R2, 2017). The desired speed is dependent on the application and driving conditions. The strategic reasons for the gearbox being a module are visualized in Figure 13.

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<thead>
<tr>
<th>Gearbox</th>
<th>Strategic Reason</th>
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<td>Carryover</td>
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<td>Technology Evolution</td>
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<td>Technical Specification</td>
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<td>Styling</td>
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<td>Upgrading</td>
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![Figure 13. Strategic reasons for gearbox module](image)

The gearbox has similar positioning within all Scania trucks (R2, 2017). The design of the gearbox has been kept stable over previous generations, which is why the module can be classified to be a *carryover module*. However, with a shift in technology towards an electrification of engines, a change or removal of the gearbox may come as a consequence.
However, the shift in technology primarily addresses the function of generating mechanical energy, which is the function of the engine. Therefore, it is not obvious that the gearbox should be classified as a technology evolution module. As carryover and technology evolution have completely different viewpoints on time it is important for Scania to determine which of the two conflicting strategic reasons that is primary. It is not possible for the same module to fulfill the strategic reason of being sustainable and valid over several generations of a product, while at the same time being changeable when exposed to external forces such as shifts in technology. This is a clear example of that it is very difficult, if not impossible, for R&D to make decisions regarding what changes should be made to the gearbox module if the department does not know what the module’s strategic reason is.

The gearbox is a module at Scania where a lot of internal improvement and development is made (R2, 2017). The cooperation with MAN entails that the gearbox will have to be changed in order to fit into a MAN chassis. These changes to the gearbox are driven by internal purposes and indicate that the gearbox should be classified to be a planned product changes module.

Scania is known for its superiority regarding manufacturing of gearboxes (R2, 2017). Scania manufactures the gearboxes in house, with few exceptions regarding certain rescue vehicles that sometimes use gearboxes from external suppliers. Separate testing is a strategic reason for the gearbox module, where the design of the module is sometimes adapted to fit Scania’s test rigs. However, the functionality of the gearbox is always prior to testing preferences. The gearbox should be classified to be a separate testing module, where the adaption of the design to fit the test rigs is a particularly strong argument for this.

The customer is entitled to choose a manual, automatic or opticruise gearbox, where the opticruise is an automatically geared manual gearbox (R2, 2017; KT1, 2017; KT2, 2017). The customer’s choice of gearbox has limitations based on the engine power (KT2, 2017). Price and the application of which the truck will be used, are other aspects that are crucial to the customer’s choice of gearbox. As the customer is entitled to choose a manual, automatic or opticruise gearbox, this module should be classified to be a technical specification module.

In addition to entire transport solutions, the gearbox is also sold separately (R2, 2017). As the gearbox is sold separately one can argue that this module should be trademarked with the Scania brand even though the gearbox is not directly visible to the customer. As a part of the collaboration between Scania and MAN, the gearbox manufactured by Scania will also be used in MAN trucks. This to utilize synergies between the two companies. However, trademarking the gearbox and making the gearbox a common component for two truck manufacturers may harm the brand. This reasoning indicates that this module may be classified as a styling module. However, styling should not be the primary strategic reason for this module. There are other modules visible to the customer, such as modules building the exterior of the cab that primarily should be classified as styling modules.
An upgrading of the gearbox rarely happens; nevertheless, the gearbox may be prepared for certain functions or bodywork (R2, 2017; KT2, 2017). A common add-on to the gearbox is the retarder, which allows a truck to slow down without using the wheel brakes. This is since the retarder automatically chooses the gear that needs to be engaged in line with the cooling and braking performance required. Preparations and variants of the gearbox are dependent on the application of the truck (R2, 2017). For instance, fire vehicles need an additional power takeoff on the gearbox to drive water pumps. For these reasons the gearbox may be considered to be an upgrading module, even though it is not the module’s strongest strategic reason.

7.1.4 Propeller Shaft

Seeing the propeller shaft as a module, its main functionality is to transmit torque and rotation from the gearbox to the axle gear (R2, 2017). The propeller shaft has a fairly simple design and the modules only vary with length and application of the truck. The strategic reasons for the propeller shaft being a module are visualized in Figure 14.

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<tr>
<th>Propeller Shaft</th>
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<td>Carryover</td>
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<td>Strategic Supplier</td>
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<td>Serviceability</td>
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Figure 14. Strategic reasons for propeller shaft module

Historically there has not been any reason to change the design of the propeller shaft, nor is there any thinkable reason why the design would be affected by new technologies in the future (R2, 2017). This indicates that the propeller shaft is a module that should be classified as a carryover module, which is defined as a module that most likely will not be exposed to any design changes during the product lifetime (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014).

The customer does not make any conscious decisions related the propeller shaft (KT1, 2017; KT2, 2017). The chosen propeller shaft is really a result of the choice of engine, gearbox and axle gear. All variants of the propeller shaft furthermore have similar design but vary in length and strength. Special requirements for this module can vary in different markets. In Brazil for example, different types of lubrication are used and this can have an impact on the
design. Attributes like varying length and strength indicate that this module could be considered a technical specification module. However, since the customer is not exposed to any direct choices related the propeller shaft and that all module variants have similar design indicate that the propeller shaft could also be considered a common unit. Common unit and technical specification are conflicting strategies and it is not possible to consider the propeller shaft as both. Looking objectively, the propeller shaft is a module that carries a function required by all customers. This is what characterize a common unit, and for that reason the propeller shaft should be classified to be a common unit module.

The propeller shaft could also be considered a strategic supplier module as Scania does not manufacture the propeller shaft itself (R2, 2017). Scania does, however, control the design of the propeller shaft completely. Development of this module therefore not only is a concern for Scania but also the supplier manufacturing the propeller shaft. This requires clear boundaries on interfaces and information regarding the design, especially since Scania is responsible for the design of this module. As suppliers manufacture the propeller shaft based on Scania’s design it is important to consider the risk of the design being turned on to competitors. The propeller shaft does not differentiate Scania’s product towards competitors, which means that this is not an imminent risk.

The propeller shaft is furthermore designed to be the weak link of the powertrain (KT2, 2017). The reason for this is that the propeller shaft is less costly to replace in comparison to the other modules related the powertrain. This indicates that this module is exposed to service and maintenance, and thereby could be classified as a service module. When developing this module, it is key to retain the flexibility to conduct service to the module. This can be accomplished through intelligently design interfaces (KT2, 2017).

7.1.5 Axle Gear

The rotating propeller shaft is attached to the axle gear (R2, 2017). The axle gear’s main function is to change the direction of the rotation and into the driving axles. The axle gear holds a gearing, which is selected based on application and fuel consumption. It also has a differential steering functionality, which enables the wheels on each side of the truck to rotate with different rotation speed. The strategic reasons for the axle gear being a module are visualized in Figure 15.
Figure 15. *Strategic reasons for axle gear module*

The axle gear is a module that is manufactured by Scania (R2, 2017). The design has looked the same through several generations of trucks, which hints that the axle gear has been a *carryover module*. There are however indications that the design might change in the future, or even that this module may go obsolete due to the demand for electric vehicles. In some of today's electric cars there is no need for axle gears, since each wheel has its own electric engine. If the electric engine, however, is placed in the same location as the engine is today there will still be a need for an axle gear. One can say that the future of the axle gear lies in the hands of the development of electric engines and its location. This reasoning indicates that this module is likely to undergo changes as a result of shifts in technology and customer demand, which are characteristics for a technology evolution module. However, one can argue that the reason for categorizing the axle gear as a technology evolution module is not directly related to the axle gear itself but rather the development of electric vehicles, and the axle gear itself is a carryover module.

In general, there are not many planned product changes to this module (R2, 2017). Changes to this module are done if field quality requests occur, which are requests based on the module’s performance on the field. If several customers are experiencing a problem with the axle gear, then a FQ request is created and a change is needed. The axle gear should for this reason be considered a planned product changes module, at least to some extent.

Scania most often produces the axle gear in house but when Scania does not hold the required performance step, and that is not very often, axle gears are sometimes bought from competitors (KT2, 2017). This is most common for trucks with two driving axles since Scania only has one performance step available for trucks with two driving axles. This may pose a risk for Scania if the competitors for some reason would change the design of the axle gear in a way so it is incompatible with the Scania design. For this reason, the axle gear could be interpreted as a strategic supplier module. However, this is only the case for a limited amount of performance steps.
The choice of axle gear is often a result of the chosen engine, where the axle gear is picked to be able to utilize the optimal engine speed (R2, 2017). The customer may have some requirements for the axle gear, most often requirements that are related to the fuel economy but this is not very common (KT2, 2017). This reasoning hints that this module is not a technical specification module.

A truck has many spots that need to be continuously lubricated and maintained (KT1, 2017). However, to be able to conduct service on the axle gear is not a primary strategic reason to why this is a module. Depending on application, there is individual service planning. This is since the service planning of a long haulage truck is not the same as for a heavy tipper truck.

### 7.2 Classification of Modules

To summarize, there are eleven different classifications of modules present in the powertrain case, and these are: carryover, common unit, service, technology evolution, technical specification, pricing, strategic supplier, planned product change, upgrading, styling, separate testing.

In addition to what the literature already has determined to be drivers for modularization, which we rather call strategic reasons, pricing has been added to be a strategic reason for modularization. Moreover, there are some drivers that have shown not to be useful in the classification of modules that form the powertrain. None of the modules were considered recyclability or process and/or organization modules. This simply indicates that the characteristics of these types of modules are not related to the powertrain. However, this does not mean that there are other modules in the truck that could be classified as recyclability or process and/or organization modules.

It is necessary to point out that there possibly are additional characteristics present in other modules, which may be strong enough to formulate additional classes of modules. However, they are not covered in this thesis, neither in the literature. The concept of classifying modules and determine their different characteristics is, in this case, what is important. Important to remember is also that some strategic reasons are incompatible.
8. Conclusions

This chapter presents the conclusions of this thesis. The conclusion connects the results and the purpose of this thesis. Generalizability of the results, empirical and theoretical contribution is also presented in this chapter. Finally, limitations and future research is discussed.

8.1 Reviewing the Purpose of the Thesis

The purpose of this thesis has been to investigate what strategic reasons R&D should consider in order to make decisions aligned with the modularization principles during product development projects. To fulfil the purpose, we first needed to answer RQ1, which focuses on how Scania is applying the concept of modularization and what implications such architecture has. The following questions both exist to answer the question why Scania is applying the concept of modularization, which was key in order to fulfil the purpose of knowing what strategic reasons R&D should consider to make decisions that support that the modularization is maintained over time. While RQ2 addresses what the company intends to achieve along lifecycle, RQ3 addresses the module-specific strategic intents. The answer, and thus the conclusion of this thesis, is presented based on the research questions.

The first research question was:

“What are the key characteristics that define a modular product architecture at Scania, and what are the managerial implications of having a modular product architecture?”

The result suggested that the bygglåda, which is referred to as a toolkit containing all pieces available at Scania to create a complete transport solution, is what characterizes the modular product architecture at Scania. The company does not develop trucks, but rather a modular system from which trucks can be created and configured through modules or components. Implications of having a modular product architecture concern five areas: product change, product variety, component standardization, product performance and product development management.

A modular product architecture facilitates product change on a component level. Decoupled interfaces that are stable over time is a prerequisite for utilizing the opportunities with having a modular product architecture at Scania. This, however, makes the modular product architecture vulnerable to disruptive technologies.

One of the most significant implications of having a modular product architecture is the ability to create a high product variety. The modular system at Scania enables the company to offer customized products to a reasonable cost. Product configurability is the strength of
Scania’s product architecture but it is also a concern as it places high demands on the information sharing between different departments.

When having a modular product architecture, component standardization is something secondary. However, component standardization is necessary in order to be lucrative while applying modularization but should only be applied to modules not visible to the customer.

Products developed from a modular product architecture are often very robust. The fact that Scania tries to control the global product performance is conflicting with what the Ulrich (1993) states, that the global product performance is not controllable with a modular architecture. However, local product performance is easily controlled when having a modular system.

Depending on what product architecture a firm chooses to apply, there are different implications on the product development management. Scania should emphasize the development of defining the product architecture itself as well as assessing component development tasks. In return Scania does not have to put as much resources on product process planning and detailed component design. To conclude, this places high demand on Scania to know where the company should allocate the resources during the development process.

The second research question was:

“What is the most important corporate strategy for applying modularization at Scania and what are the strategic reasons for applying modularization along the lifecycle phases?”

The result suggests that the most important corporate strategy for applying modularization at Scania is to offer the appropriate variation to meet the high and varying customer needs. This is enabled through configurability, which enables Scania to mass produce and customize the product simultaneously.

At Scania there are nine different strategic reasons for modularization during the different phases of the product lifecycle. The phases of the product lifecycle are R&D, Production, Customer and Aftermarket. R&D seems to play a central role, regarding Scania’s company specific strategy of meeting a high variation in customer needs, where the strategic reasons are technology evolution, planned product changes, common unit, carryover and separate testing. For Production, the strategic reasons for modularization at Scania are common unit, carryover, process and/or organization and strategic supplier. For Customer, the strategic reason is technical specification, which is also the strategic reason that is most similar to Scania’s corporate strategy. Eventually, the main strategic reason during Aftermarket is serviceability.
Several respondents at Scania stressed that time to market and costs were strategic reasons during different lifecycle phases. However, we argue that time to market and costs are of a different nature compared to the other strategic reasons given by the respondents. Time to market and costs may be seen as a result of several other strategic reasons. Furthermore, configurability was mentioned as a strategic reason for production. We argue that configurability should not be characterized to be a strategic reason for modularization, but rather a means to reach the strategic goal of having a well-functioning production, process and/or organization.

The third research question was:

“How are different modules related to different strategic reasons for modularization at Scania?”

Through the conceptualized example of the powertrain we have shown that there are different strategic reasons for modules. Assuming that the powertrain is divided into the five modules engine, clutch, gearbox, propeller shaft and axle gear, we have shown that there are eleven different strategic reasons for the different modules forming the powertrain. The engine is considered a module that is ever changing and therefore planned product changes and separate testing are the strategic reasons for this module. The engine is also considered a module that is closely connected to the customer intimacy strategy. As the engine has several performance steps available to the customer the engine is also classified to be a technical specification module. In addition to the strategic reasons found in literature, the respondents also bring up pricing as a strategic reason for the engine. The clutch is a module clearly connected to strategic reasons related to the operational excellence strategy. The clutch is considered a carryover, common unit as well as a strategic supplier module. The gearbox is a module that is difficult to classify, the result shows that the gearbox is connected to many strategic reasons, which are sometimes conflicting. The fact that this module is connected to many strategic reasons indicates that the module needs to be further decomposed to gain the maximum benefit from the classification. As for the clutch, the propeller shaft is clearly classified to be a module connected to the operational excellence strategic reasons with the difference of also being considered a serviceability module. Finally, the axle gear is simply considered to be a carryover module.

To conclude, we have shown that there are different strategic reasons for modules. The result of understanding the different characteristics of the modules is important when developing modules at R&D as the classification of modules can function as base for decision-making during development projects. Knowledge about the characteristics of a module can indicate what is allowed and what is not allowed to change for the specific module.
8.2 Generalizability of the Results

Since this is a case study, the generalizability is limited in its nature. However, other manufacturing firms that have a modular product architecture could find the results from this study usable. The study is relevant for and can be generalized to manufacturing companies utilizing modularization regarding the implications such product architecture brings. However, the parts of this thesis that regard strategic reasons are specific to the case Scania. Naturally, companies having a different strategic focus with modularization, have differently modularized products and other strategic intents. Even though the actual conclusion regarding the strategic reasons can not be generalized for any company manufacturing physical products, such companies can still use the insight regarding that strategic reasons can be lifecycle phase specific and module specific.

8.3 Empirical Contribution

A case study has been performed at Scania. Classifying modules in a systematic way, with purpose to support the decision-making process during product development projects, challenges Scania’s view on modularization. The conceptualized example (the powertrain) is presented to demonstrate what a classification could look like. In other words, this means that the conclusion of this thesis contributes with a new way of relating to modularization at Scania.

8.4 Theoretical Contribution

This thesis contributes to theory with a new area of use for the modular drivers. The literature claims that the drivers for modularization primarily should be used as the basis for the creation of modules. We, on the other hand, argue that the modular drivers could be interpreted as strategic reasons and furthermore utilized when analyzing characteristics of modules with purpose to classify different modules.

8.5 Limitations & Future Work

As of today, a truck does not only consist of physical components but also a lot of software solutions. This thesis only concerns modularization of the physical parts of a product and for that reason further work that includes software is needed.

The level of detail in which the classification of modules should be done is not decided in this thesis. For that reason, there is a need for further work regarding what module level the classification should be made. Also, the scalability of a classification of modules needs to be further investigated.
This thesis concludes that a classification of modules could function as a base for decision-making during development projects. However, this thesis does not include how the classification methodology should be implemented in an organization.

Our choice of only interviewing people from R&D naturally reflects our results. As modularization concerns all divisions within a company, we suggest to include all divisions in order to reach a more diversified result.
9. Discussion

This chapter contains a discussion of the research analysis and the conclusions drawn. More specifically we discuss how the research analysis and the conclusions drawn impact modularization both in general and at Scania. The discussion of the findings is according to the sectioning of the thematic analysis.

9.1 Product Architecture

One of the respondents suggests that Scania tries to control the performance of the truck as a whole from several modules, what in literature is described as global product performance (Ulrich, 1993). Furthermore, Ulrich (1993) claims that it is not possible to successfully control the global performance of a product when having a modular product architecture. Consequently, controlling the global product performance becomes a challenging task for Scania. It is furthermore important for Scania to understand the limitations with having a modular product architecture in controlling the global product performance. In order to maintain the modularization over time, Scania should consider the global performance as something secondary and instead focus on optimizing modules, meaning the local performance.

A modular variant can be developed or optimized according to an integral design, which means that a coupled design and many-to-one relationship between function and technical solution is allowed for the development within module variants (Ulrich, 1993). Optimization according to an integral product architecture however requires a clear definition of how far the modular architecture extents. If the modular system does not clearly define the modules, it is not clear where the optimization according to the integral design can be made. The fact that Scania does not have clearly defined modules, but rather component series, complicates the optimization within module variants through an integral design.

9.2 Strategic Reasons for Modularization

What Ericsson and Erixon (1999) among others describe to be different drivers for modularization, we suggest instead should be seen as strategic reasons for modularization, namely something that can be achieved through having a modular product architecture. We see them as strategic reasons as they are used to serve the company’s strategic intents. The fact that the drivers cover the entire product lifecycle is a way to consider the needs and strategic intents of different stakeholders of the product (Ericsson & Erixon, 1999). How strategic reasons are linked to different functions within a company, and different phases within the product lifecycle, is something that needs further investigation at Scania. One module can have a strong strategic reason within production but have another strategic reason, strong or weak, during another phase, such as aftermarket. We suggest that a holistic view of
the entire lifecycle is necessary to be able to classify modules and thus strengthen the modularization concept.

What is important for Scania to consider is the character of the strategic reasons. In literature all strategic reasons are of the same character, namely something that can be achieved through a modular product architecture and that serves the company’s strategic intents (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014). During interviews we experienced suggestions such as time to market and cost reduction as examples of strategic reasons, but we argue that these are of a different character and that they may be seen as a result of the strategic reasons. Scania would have to anchor the definition and meaning of the strategic reason in the entire organization. How this should be done, is something that needs further investigation. In similar reasoning to that Scania needs to have a common nomenclature and clear definitions and documentation within the product structure, it is necessary to have a common nomenclature, definition and documentation of strategic reasons.

9.3 Strategic Reasons in Different Modules

The concept of modularization is ambiguous. This became clear during our interviews as we got as many definitions of a modular product architecture as respondents. Development of clear definitions becomes a necessity for Scania as a classification of different modules requires a common nomenclature, a clearly defined modular system and well documented interfaces. This is of particular importance as the accuracy of defined modules reflects the accuracy of the classification of strategic reasons.

The level of detail plays a central part when classifying different modules. We chose to divide the powertrain into five modules. However, we understood that the powertrain itself can sometimes be considered a module but also that each of the modules we chose could be further divided into modules. This naturally affects what the strategic reason for the module will be. For that reason, it is necessary to carefully decide the level of detail when classifying modules. How to determine what level of detail will bring the most value to the decision-making during development projects is something that needs further investigation. In general, there is a trade-off between the level of detail and the simplicity of the result. Again, the accuracy of the division of modules reflects the accuracy of strategic reason.

Each module should have a clear purpose (Modular Management, 2012b; Ericsson & Erixon, 1999; Lange & Imsdahl, 2014), additionally we have found that some strategic reasons also can be module variant specific. This means that a strategic reason may only be applied to a certain module variant. We, for instance, identified pricing as a strategic reason for some of the module variants of the engine. These module variants function as entry performance steps, with purpose to attract the customer to chose a higher performance step which is more lucrative for Scania. Being classified as a pricing module implies that this specific module
variant should not get too much attention in terms of development, as its initial purpose is not to be sold to a large extent. One of the modularization principles at Scania implies to have balanced performance steps, which means that Scania should only hold the requested performance steps in the *bygglåda*. One can however argue that this strategy of having entry performance steps in the *bygglåda* is against the principle of having balanced performance steps.

With pricing as an example of a module variant specific strategic reason, there may be other strategic reasons that are addressing the module variant level. This is something that needs further investigation. As entry performance steps are concerns for sales & marketing, it would be an idea to involve other stakeholders other than R&D when doing the investigation. This way it could be possible to identify what other types of strategic reasons that exist.

Eventually, some module classifications have proven to be application specific. For example, depending on application a certain module may or may not be considered a service module. A propeller shaft used in an application with tough road conditions can be considered a service module while a propeller shaft used for long haulage might not be considered a service module. This can be helpful for Scania during the development processes.
References

Articles and Publications


Books


**Web Documents and Sites**


**Consultancy Report**

PowerPoint Presentation


Appendix A: Interview Guide

Introduction Questions
1. What is your role in the company and what are your main work tasks?
2. How long have you been working here?
3. How would you briefly define the concept of modularization, in general and at Scania?

Product Architecture
4. How would you briefly define a modular product architecture and how does it differ from other product architectures?
5. What is the main reason for applying a modular product architecture?
6. How does a modular product architecture facilitate product change?
7. How does a modular product architecture limit your ability to change products?
8. How does a modular product architecture facilitate product variety?
9. How does a modular product architecture limit your ability to create variety in products?
10. How does a modular product architecture facilitate product component standardization? (the use of the same component in multiple products)
11. How does a modular product architecture limit your ability to create component standardization?
12. How does a modular product architecture facilitate product performance?
13. How does a modular product architecture limit product performance?
14. How does a modular product architecture facilitate the product development process?
15. How does a modular product architecture limit the product development process?

Some literature argue that there are different drivers for modularization along the product lifecycle, and in this case we have divided the product lifecycle into 5 phases, R&D, Manufacturing/Purchase, Production/Assembly, Customer and Aftermarket. We will now ask questions regarding each phase, starting with research and development.

Research & Development
16. What are the main drivers for having a modularized product architecture during the development process of a product?
17. How is different development projects inhibited by having a modularized product architecture?
Manufacturing/Purchasing
18. What are the main drivers for having a modularized product architecture when manufacturing different parts?
19. How is the manufacturing of parts inhibited by having a modularized product architecture?

20. What are the main drivers for having a modularized product architecture when buying in different parts and/or subassemblies from external suppliers?
21. How is the buying in from external suppliers inhibited by having a modularized product architecture?

Assembling/Production
22. What are the main drivers for having a modularized product architecture when assembling the product?
23. How is the assembling of products inhibited by having a modularized product architecture?

Customer
24. What are the main drivers for having a modularized product architecture in terms of meeting the customer needs?
25. How are attempts of meeting the customer needs inhibited by a modularized product architecture?

Aftermarket
26. What are the main drivers for having a modularized product architecture regarding aftermarket?
27. How is the aftermarket inhibited by a modularized product architecture?

Wrap up questions
28. What are the challenges in the future regarding modularization?
29. Which aspects are most critical?
30. Any last comments?
Quantitative Questions

Some literature argues that there are certain drivers for modularization. Please give your ranking based on relative importance in terms of grading modularization at Scania. Rank the drivers on a scale from 1-12, where 1=least important driver for modularization and 12=most important driver for modularization. Only one driver per numerical value.

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<th>Drivers</th>
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<tbody>
<tr>
<td>Separate testing (independent testing of functions, which shortens feedback times and improves quality)</td>
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<td>Carryover (a reuse of parts, subsystems or technology over different generations within the product platform)</td>
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<td>Strategic supplier (making conscious decisions on whether to manufacture certain parts or sub modules in-house or to buy in from available suppliers)</td>
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<td>Common unit (parts that can be used for large shares of the entire product assortment)</td>
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<td>Process/Organization (having an efficient production, where parts that demand the same production processes are moved to the same module)</td>
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<td>Planned product changes (changes of parts due to internal forces, such as a launch of a product, better fulfil certain customer demand or decrease production costs)</td>
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<td>Technology evolution (changes within parts due to a change in customer demand or technology shift; strategic technological development that are driven by external forces)</td>
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<td>Technical specification (allocate all variations to as few product parts as possible)</td>
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<td>Styling (changes in styling or design that are visible to the end customer, a brand-driven variance in appearance)</td>
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<td>Serviceability (new module can quickly replace a damaged one, by well-designed interfaces)</td>
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<td>Upgrading (the product lifetime can be prolonged or the product performance improved)</td>
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<td>Recyclability (limiting the number of different materials in each module)</td>
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If you would like to add any other driver for modularization that you think is important to consider when measuring the grade of modularization, please state it below and give a short explanation on why you think it is important:

____________________________________________________________________________________________
____________________________________________________________________________________________
Appendix B: Interview Guide - Powertrain

Introduction
1. What is your role in the company and what are your main work tasks?
2. Would you agree that engine, clutch, gearbox, propeller shaft and axle gear corresponds to the actual modular structure of the powertrain?
   IF NO: How would you divide the powertrain into modules, at similar high level?

Module specific strategic reasons
For each of the modules engine, clutch, gearbox, propeller shaft and axle gear, the following questions were asked to R&D:

3. What is the main functionality of the module?
4. Carry Over: Are there (strong, medium, weak) reasons that the design of this module will be carried over to coming generations?
5. Technology Evolution: Is it a (strong, medium, small) risk that this module will go through a shift in technology during the lifetime of the product?
6. Planned Product Changes: Are there (strong, medium, weak) reasons that this module carry attributes that will be changed according to product plan?
7. Technical Specification: Is this module (strongly, fairly, weakly) influenced by varying requirements?
8. Styling: Is this module (strongly, fairly, weakly) influenced by styling trends so that for instance form/color will be changed?
9. Common unit: Can this module have the same physical form in (all, most, some) of the product variants?
10. Process/Organisation: Are the production processes a (strong, medium, weak) reason to why this is a module?
11. Separate Testing: Is the ability to test the module separate to others a (strong, medium, weak) reason to why this is a module?
12. Strategic Supplier: Is there a (strong, medium, weak) reason for this module’s existence to be bought in from a supplier?
13. Serviceability: Is the ability to conduct service on this module a (strong, medium, weak) reason to why this is a module?

14. Upgrading: Is the ease of upgradeability a (strong, medium, weak) reason to why this is a module?

15. Recyclability: Is the recyclability a (strong, medium, weak) reason to why this is a module?

For each of the modules engine, clutch, gearbox, propeller shaft and axle gear, the following questions were asked to Sales & Marketing (the functionality of each module is based on information received from R&D):

16. What direct choices regarding the module is available to the customer, given its functionality?
17. What types of upgrading of this module occur at the request of the customer?
18. What types of service does the customer have to conduct on this module?
Appendix C: Result - Quantitative Questions

The table presents the result from the quantitative questions, which were asked during the interviews. The respondents were asked to give their ranking of strategic reasons based on relative importance in terms of grading modularization at Scania. The strategic reasons were ranked on a scale from 1-12, where 1=least important driver for modularization and 12=most important driver for modularization. The respondents were allowed to give the same numerical value to only one strategic reason.

<table>
<thead>
<tr>
<th>Strategic Reason</th>
<th>Sum</th>
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<tr>
<td>Separate Testing</td>
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<tr>
<td>Carryover</td>
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<tr>
<td>Strategic Supplier</td>
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<td>49</td>
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<tr>
<td>Common Unit</td>
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<td>Process/Organisation</td>
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<tr>
<td>Recyclability</td>
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<tr>
<td>Planned product changes</td>
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<td>69</td>
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<tr>
<td>Technology evolution</td>
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<td>Technical specification</td>
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<td>Styling</td>
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<td>Serviceability</td>
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<tr>
<td>Upgrading</td>
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<td>63</td>
</tr>
</tbody>
</table>

- Green = Operational Excellence
- Blue = Product Leadership
- Pink = Customer Intimacy