TEKNILLINEN TIEDEKUNTA

Technical product portfolio: standardization by component commonality

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Industrial Engineering and Management
Master’s thesis
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ABSTRACT FOR THESIS

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Abstract

One key element when considering research and development (RnD) design decisions is the final cost of the product. A big part of the product cost comes from the component costs, also known as the bill of materials (BOM) costs. In industries, the focus on reducing the cost of every single component may lead to a situation, where almost identical solutions are implemented with different components. Furthermore, the increasing amount of product variety demanded by the markets increases the number of components that need to be managed even further. This research focuses on the aspect of using common components for different products. The research consists of a literature review and a case study.

The aim of this study is to understand what the benefits and the limitations of using component commonality are, and how it can be used to a company's benefit. The aim of the case study is to analyze the current state of the component commonality in the case company's products. Furthermore, opportunities to improve the component commonality are identified, and the effects are estimated. According to the results, the solutions for how the component management should be improved in the case company are suggested.

This research was conducted by reviewing the scientific literature around the concept of product and component management, and then more precisely, on the component commonality approach. The scientific literature provided insights into the benefits and limitations of component commonality could be. Based on this, the current state of the company's component commonality was analyzed. The products were analyzed using a chosen commonality index found in the literature. Bill of material (BOM) data were used in the analyses.

The analyses suggested that using common components is indeed possible for the products: higher commonality was observed among the products developed in a single RnD site in comparison to the commonality of the products of separate RnD sites. A development point was observed in improving the cooperation between different RnD sites, to be able to use common products throughout the company's product portfolio. A technologically feasible development opportunity to improve this cross-site cooperation was found in connector components. The monetary gains of using common connectors were estimated using a heuristic approach and a notable reduction in the costs was observed. An organizational body to improve the co-operation was recognized, and the research findings were discussed with them.

Additional Information

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Tiivistelmä

Lopputuotteen kustannus on yksi keskeinen asia, joka tulee huomioida tehtäessä tuotekehitykseen liittyviä päätöksiä. Iso osa lopputuotteen kustannuksista koostuu tuoterakenteen komponenttien yhteenlasketusta hinnasta, eli niin sanotusta ”BOM” -hinnasta (bill of materials). Fokusoituminen hinnan vähentämiseen komponenttitasolla voi johtaa tilanteeseen, jossa samanlaisia suunnitteluratkaisuja tehdään eri komponenteilla. Lisäksi vaihtelevan tuotevalikoiman kasvava kysyntä lisää tarvittavien komponenttien määrää vielä entisestään. Tämä tutkimus keskittyy siihen, kuinka yhteisiä komponentteja voidaan käyttää eri tuotteiden välillä. Tutkimus koostuu kirjallisuuskatsauksesta sekä tapaustutkimuksesta.

Tutkimuksen tavoitteena on ymmärtää mitä hyötyjä ja haittoja yhteisten komponenttien käytöllä on, ja kuinka niitä voidaan käyttää yrityksen hyödyksi. Tapaustutkimuksen tavoitteena on selvittää, kuinka laajasti yhteisiä komponentteja käytetään yrityksen tuotteissa. Lisäksi halutaan löytää mahdollisuuksia yhteisten komponenttien käytön lisäämiselle ja arvioida mitä hyötyjä tämä toisi. Yritykselle esitetään tutkimuksen tulosten mukaisesti rakennetut kehitysehdotukset.

Tutkimuksen kirjallisuuskatsaus -osiossa tarkasteltiin tuote- ja komponenttihallinnan tieteellistä kirjallisuutta, keskittyen yhteisten komponenttien käyttöä koskevaan kirjallisuuteen. Kirjallisuuskatsauksessa opitun pohjalta tehtiin tapaustutkimus, jossa case-yrityksen nykytila arvioitiin yhteisten komponenttien osalta. Analyyseissä käytettiin kirjallisuudessa löydettyä indeksiä, jonka käyttäminen vaati tuoterakennetiedon (BOM).

Analyysien tulokset viittasivat siihen, että case-yrityksessä oli parantamisen varaa yhteisten komponenttien käytössä. Parempaa yhteisten komponenttien käyttöä havaittiin niiden tuotteiden välillä, jotka oli suunniteltu samassa tuotekehitysyksikössä. Yhteisten komponenttien käyttöä voitaisiin siis kehittää parantamalla tuotekehitysyksiköiden välistä yhteistyötä. Teknologisesti toteuttamiskelpoinen kehitysalue löydettiin liitinkomponenteissa. Liitinkomponenttien yhteiskäytön parantamisen tuomat kustannushyödyt arvioitiin heuristisella menetelmällä. Yhteisten liitinkomponenttien käytön lisäämisen todettiin tuovan mahdollisuuksia selviin kustannussäästöihin. Yrityksen sisällä löydettiin yksikkö, joka pystyy käytännössä toteuttamaan tässä työssä esiin tuodut kehitysehdotukset. Tutkimuksen tulokset käytiin läpi tämän yksikön kanssa.

Muita tietoja

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ABBREVIATIONS AND DEFINITIONS

BOM	Bill of materials
DCI	Degree of commonality index
KPI	Key performance indicator
NPD	New product development
PCB	Printed circuit board
PLM	Product life cycle management
PPM	Product portfolio management
RnD	Research and development
TCCI	Total constant commonality index
Unique component	A component that is the only one of its kind found in the observed set. For example, in group ABBCCCD, there are only two unique letters: A and D. In spoken language, “unique” may sometimes be used incorrectly in place if “distinct”.
Distinct component	Component, which is recognized as different from other components. For example, in group ABBCCCD, there are four distinct letters: A, B, C, and D.
Economies of scale	Cost advantages a firm can experience when it increases its level of output.

1 INTRODUCTION

1.1 Study background

In the tightening competition for market share in today's technology business, any opportunity to provide customers with products of increasing variety and quality, yet decreasing the cost is beneficial to a business (Vakharia, Parmenter and Sanchez, 1996; Perera, Nagarur and Tabucanon, 1999; Bi and Zhang, 2001; Salvador, Forza, and Rungtusanatham, 2002; Ramdas, 2003; Mikkola, 2006; Fixson, 2007; Hernandez-Ruiz *et al.*, 2016). One studied approach to increasing customizability without increasing the investments in research and development (RnD) or increasing operating costs is through the use of common components (Starr, 1965; Jiao and Tseng, 2000; Swaminathan, 2001; Fixson, 2007; Hernandez-Ruiz *et al.*, 2016).

Using common components results in a smaller component portfolio (Jiao and Tseng, 2000). This can reduce the needed RnD resources when past designs can be used (Hopson, Thomas, and Daniel, 1989), reduce the sourcing costs by lowering the needed safety stocks as well as by increasing the purchase quantities and thus providing economies of scale benefits (Dogramaci, 1979; Collier, 1981, 1982; Baker, 1985; Gerchak and Henig, 1989; Hillier, 2002; Hernandez-Ruiz *et al.*, 2016). The reduced amount of component items that need to be managed reduces the planning complexity (Collier, 1981, 1982; Vakharia, Parmenter, and Sanchez, 1996) and may also improve the quality management of the components. Set-up times in production may also be reduced (Collier, 1981).

Possible drawbacks to using component commonality also exist (Dogramaci, 1979; Jiao and Tseng, 2000). For a myriad of reasons, achieving component commonality among certain products can be simply impossible (Korhonen *et al.*, 2016). Furthermore, the goal to achieve higher component commonality should not limit the development of new and improved components, and they should rather be developed among the many development activities of programs and projects within the RnD activities (Korhonen *et al.*, 2016).

Measuring the level of commonality has been researched throughout the years, and quantitative methods have been developed (Collier, 1981; Jiao and Tseng, 2000; Fixson, 2007). However, trying to deduct what level of commonality would be the most beneficial has proven to be difficult (Rutenberg and Shaftel, 1971; Dogramaci, 1979; Jiao and Tseng, 2000; Korhonen *et al.*, 2016). In some specific cases models have been developed, but mostly heuristic approaches have been taken (Rutenberg, 1971; Dogramaci, 1979; Baker, 1985; Gerchak and Henisg, 1989; Vakharia, Parmenter and Sanchez, 1996; Nagarur and Azeem, 1999; Jiao and Tseng, 2000; Hernandez-Ruiz *et al.*, 2016). Still, on a more general level, it remains a major challenge (Baker, 1985; Korhonen *et al.*, 2016).

1.2 Research problem and objective

The case company that commissioned this research had found interest in standardization as it likely brings advantages in a tight competition of the market share. The company was looking for a way to improve its current practices. The case company was interested to pursue research to reveal how well they are using common components in their products and find out whether there is room for improvement. Here, the specific research questions for which the study aimed to answer were the following:

1. What are the common themes in component standardization and component commonality management in the scientific literature and how can they be used to the company’s advantage?
2. What is the current state of component commonality in the case company?
3. How could the component commonality be improved in the case company?

With the previous in mind, a research approach was planned firstly, to research the scientific literature based on the area. The focus was on the best practices in standardization and component commonality management and ways to analyze them. This provided an answer to research question one, presented in section 2 Literature review. Secondly, in section 3 Case study – Current state analysis of the case company, this research analyzed the company’s current situation concerning the themes raised in the literature; a case study on the case company’s products was conducted using the methods and lessons learned in the literature review. Finally, the third research question was answered in section 4 Development ideas: compiling the conclusions from the case study, the ideas for how the component management could be improved in the case company were generated.

1.3 Research process

This research was implemented as a case study for the company *Nokia Solutions and Networks*. Nokia is a multinational telecommunications and information technology company. In this case company, a need to study the possible “re-use” of certain component types had risen. In the company “re-use” is used as a term to describe what scientific literature defines as ‘component commonality’. In scientific literature ‘re-use’ implies a product design, where the specific components are planned to be re-used after they have served their purpose in the life-cycle of the first product (Mangun and Thurston, 2002). To avoid confusion, the term “re-use” is not used in this study, but instead, we use the term “component commonality”.

During the initial talks with the case company, the proposed approach for the study was to first understand the current situation of the company and their understanding of their current needs. Secondly, to go through the current scientific literature covering the raised needs, and finally, to apply the recognized theoretic findings for Nokia’s case. The proposed study plan was discussed, modified, and agreed with the case company.

After the discussions, the specific aims of the study were refined. The final aims of the study were to research the component commonality and standardization literature and based on those findings to analyze the technical product structures of multiple different products of Nokia, and to present a current state evaluation. Finally, the possible areas for future research were to be identified, and suggestions for further development actions were to be formed. To fulfil these needs, the scientific research, presented in this thesis paper, was then planned. The research process is presented in Figure 1.

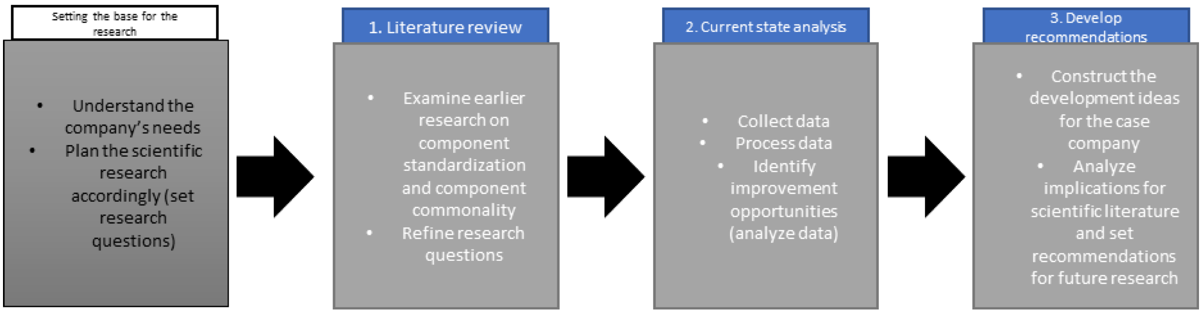

Figure 1, Research process

The process started by firstly understanding what the commissioning company was looking for and by familiarizing with the company itself. The scientific research was planned once understanding and rapport had been established with the case company. The research process continued as case studies mostly do. The literature review was conducted, in which various academic publications were used. The learnings of which were then used in practice to analyze the case company.

The company was analyzed by conducting a case study, in which quantitative research methods were used to construct a current state analysis: empirical data were received from the company, and it was analyzed using correlational methods. Ultimately, development recommendations were constructed based on the current state synthesis. More precise description of the research method is presented in chapter 3.2 Research method and data collection.

2 LITERATURE REVIEW

2.1 Product

When defining the concept of a product, different perspectives can lead to various definitions (Peltonen, 2000). The simplest definition of a product is that it is anything that can be sold (Haines, 2014). Furthermore, a product can be defined either as tangible or intangible (Kahn *et al.*, 2012; Haines, 2014; Harkonen, Haapasalo, and Hanninen, 2015; Stark, 2016). Tangible products are all physical goods that can be manufactured and sold, such as toilet paper and food products, and more complex items such as mobile phones and televisions (Jacobs and Swink, 2011; Harkonen, Haapasalo, and Hanninen, 2015). Intangible products can be software-based; including programs, documents, and data for delivery to users, for instance, the data that a service provider such as Facebook sells of its users to marketing companies and so on (Fricker, 2012; Harkonen, Haapasalo, and Hanninen, 2015). In addition, also services are intangible products (Harkonen, Haapasalo, and Hanninen, 2015). For example, traditional services such as barbershops and massage parlors, as well as more modern ones such as streaming services, for example, Netflix. Netflix provides its users with a movie platform on the internet browser of their computers or other devices. The product can be any sort of combination of these tangible and intangible elements that composes a solution to a customer's need (Harkonen, Haapasalo, and Hanninen, 2015).

2.2 Product structure

For a company to understand what it is selling, and what it needs in order to supply the product to its customers, it needs to understand the structure of its product. The product structure consists of the product data, which includes the components and properties, and their relation to the product itself. (Crnkovic, Asklund and Dahlqvist, 2003; Zhang, Shen and Ghenniwa, 2004; Saaksvuori and Immonen, 2008) In practice, a product structure can be a hierarchical division of all the parts that make the product (Svensson and Malmqvist, 2002; Crnkovic, Asklund, and Dahlqvist, 2003). The highest level would be the main assembly, followed by the sub-assemblies that make the assembly, and finally the components that are parts of the assemblies (Janardanan, Adithan, and Radhakrishnan, 2008). The Bill of Material (BOM) typically depicts this product structure.

Product structure helps to manage different variants of a product (Kropsu-Vehkaperä, 2012). A common model for the products throughout the company is necessary: it improves product data management in various information systems, which often may be used for decision making (McKay, Erens and Bloor, 1996; Svensson and Malmqvist, 2002). Once a good product structure has been defined, it can be managed in product data systems (Kropsu-Vehkapera *et al.*, 2011).

Figure 2 shows a typical way of managing product structure. The highest level of the hierarchy, Solution, can be comprised of multiple different product families, all of which can have different configurations. The product families contain a collection of product configurations that are either aimed towards the same kind of customer need or are built on the same technological platform. For example, a bike manufacturing company might have product families for children's bikes and mountain bikes, but most likely the families are based on the technology platform such as the used bike frame type. The product configuration represents the collection of pre-designed sales items that can be chosen. (Tolonen, Kropsu-Vehkapera and Haapasalo, 2014; Tolonen, 2016)

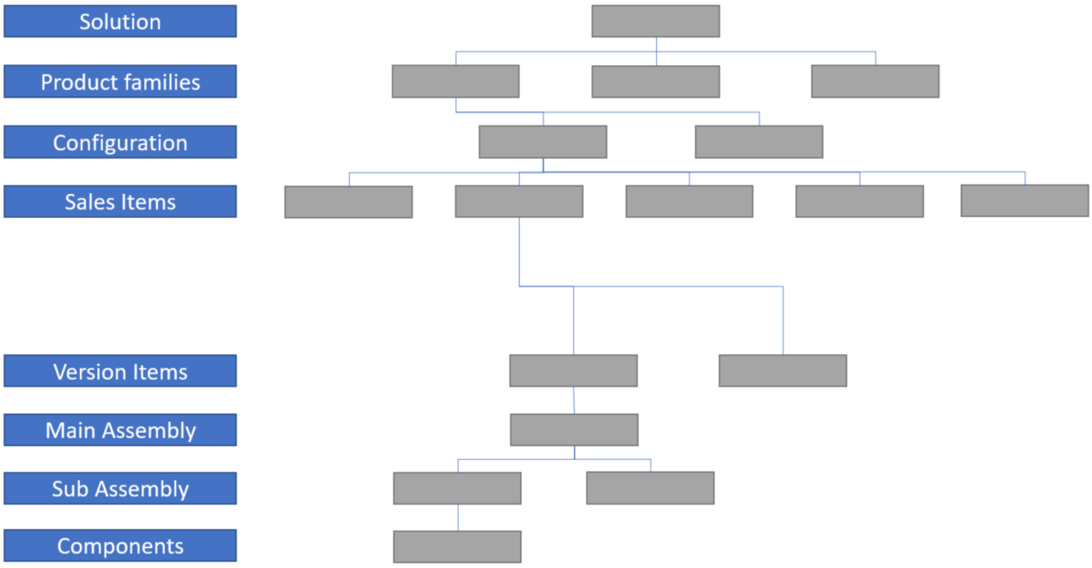

Figure 2, Product structure, modified from (Tolonen, 2016).

The sales item is the lowest level that can be sold. In the context of a bike manufacturing company, the product configuration could be a mountain bike of specific frame technology, to which the customer has chosen the transmission, tires, brakes, and a saddle, all of which would be classified as sales items. A sales item can have multiple revisions of the version items. Newer versions of the same items are often developed and made to improve cost efficiency or other factors such as user experience or reliability (Kropsu-Vehkapera *et al.*, 2011). A variant is defined as a group of alternatives, out of which one is selected, while an option is something that can either be selected or left out (Kropsu-Vehkapera *et al.*, 2011). Put simply: a new version item replaces the previous one, while a variant extends the product family (Kropsu-Vehkapera *et al.*, 2011). The main assembly represents the highest level of assembly from a manufacturing perspective. Sub-assemblies, that consist of the components, when assembled, form the main assembly. Components include all parts that cannot be divided into smaller parts. For example, all the screws are components, but the largest part of the bike, the frame, also may be only one component, if it has been made from a single aluminum casting, for instance. The product structure can be divided into the commercial structure and technical structure between the sales and version items (Harkonen, Tolonen, and Haapasalo, 2017, 2018). (Tolonen, Kropsu-Vehkapera and Haapasalo, 2014; Tolonen, 2016)

Managing the product structure in this way gives the benefit of viewing it in the way that is most beneficial for the given purpose. For example, the departments responsible for the solution-level design are typically not interested in the specifics of what the product is made of, meaning that they do not need the information concerning the sub-assembly or component contents of the product. Hence, the more functional view of the commercial side is more appropriate for marketing, sales, and product management. For manufacturing, testing, and product development, for instance, assembly and component levels of the division are likely to be more important. (Tolonen *et al.*, 2015)

2.3 Increasing product variety

Mass customization has risen as a solution to meet the needs of individual customers (Pine, 1993; Fixson, 2007). Customization focuses on the differences between products, which are targeted at different customers. The increase in the product portfolio, however, will inevitably lead to an increase in costs, as unnecessary design efforts are likely to be done without proficient standardization practices (Vakharia, Parmenter and Sanchez, 1996; Jiao and Tseng, 2000). Also, inefficiencies may occur in manufacturing, as well as in the support functions such as purchasing, product costing, and inventory control (Jiao and Tseng, 2000). Without standardization, designers will most likely end up designing new parts each time when there are plans for a new product (Jiao and Tseng, 2000).

Configurable products make it possible for a customer to have the product built to his specific needs without the need to design new components (Tiihonen *et al.*, 1998; Salvador, Forza, and Rungtusanatham, 2002; Forza and Salvador, 2006). Configurable products are seen as a way to improve product development and operational efficiency while maintaining product variety (Hvam, Mortensen, and Riis, 2008; Zhu *et al.*, 2008). A product configuration is a selection of chosen parts, all of which have been well defined, and the interactions of which are known (Sabin and Weigel, 1998). A product can be seen as configurable if it is visible to the customer in the commercial product structure in such a way, that variants and options can be selected for the final product (Pulkkinen, 2007; Hvam, Mortensen, and Riis, 2008).

Modularity is what provides the technical ability to build configurable products (Tiihonen *et al.*, 1998). One definition of modularity is the ability to use the designed modules or parts as components in different end products (Starr, 1965; Dogramaci, 1979). Modularity has emerged as a solution to answer the increasing demand for product variety (Starr, 1965; Dogramaci, 1979; Fixson, 2007). It provides a means to increase commonality between products within the product family (Salvador, Forza, and Rungtusanatham, 2002). As the result, the same parts of the products are used across the variants. (Bruun *et al.*, 2015)

Product family development practices have also been used to optimize the operational complexity resulting from product variety (Meyer, Tertzakian, and Utterback, 1997; Robertson and Ulrich, 1998). Development of the product families provides means to be able to reuse proven elements in the product range of the company to achieve economy of scale benefits (Ishii, Juengel and Eubanks, 1995; Tseng, Jiao and Merchant, 1996; Robertson and Ulrich, 1998; Jiao and Tseng, 2000). In practice, the product family is designed in a way that it consists of similar products, that share the same version of certain components and/or its sub-modules. In addition to the economy of scale benefits, product family designs offer multiple other benefits such as reduction of development risks, improved flexibility in the manufacturing process, more responsive manufacturing, and a better ability to upgrade products (Sawhney, 1998). (Bruun *et al.*, 2015)

Similar benefits as described above can be obtained with practices that aim to increase component standardization (Perera, Nagarur, and Tabucanon, 1999). The degree of component standardization has been defined as the mean number of applications, that can use the same component (Roque, 1977; Jiao and Tseng, 2000). Consequently, product family practices increase component standardization and can be defined as a component standardization practice. Component standardization, however, can therefore be pursued in addition to product family development practices.

2.4 Component Commonality

The component commonality is one of the product structure characteristics, that has been studied when searching for new means to improve standardization and reduce internal complexity (Dogramaci, 1979; Collier, 1981; Wacker and Treleven, 1986; Jiao and Tseng, 2000; Fixson, 2007). Fischer et al. (Fisher, Ramdas, and Ulrich, 1999) describe component commonality as the use of the same version of a component in many different products. Component commonality has been used increasingly in the high technology business (Fixson, 2007). This approach helps the company to be able to offer a higher variety of products while maintaining the costs as low as possible (Starr, 1965; Swaminathan, 2001; Fixson, 2007; Hernandez-Ruiz *et al.*, 2016). Component commonality indeed is a good way to increase standardization through the product portfolio (Collier, 1981; Fixson, 2007).

2.4.1 Benefits and limitations of component commonality

Previous studies suggest that a higher degree of commonality, i.e. higher degree of common components in the company's products reduces costs in many of the product's life cycle phases (Dogramaci, 1979; Collier, 1981, 1982; Baker, 1985; Perera, Nagarur and Tabucanon, 1999; Hernandez-Ruiz *et al.*, 2016). This is achieved mainly by reducing inventory costs and set up costs, as well as by risk pooling due to economies of scale (Dogramaci, 1979; Collier, 1981, 1982; McClain *et al.*, 1984; Baker, 1985; Hernandez-Ruiz *et al.*, 2016). Higher commonality helps to increase pooling quantity and to reduce timing uncertainty (Dogramaci, 1979; Collier, 1982).

In production, component commonality can reduce setup times (Starr, 1965; Collier, 1981, 1982; Maimon, Dar-El and Carmon, 1993). Cost savings in procurement due to economies of scale and order pooling may be significant (Hillier, 2002). Collier demonstrated how a higher degree of component commonality reduced prices in certain lot-size purchasing models (Collier, 1981). It is difficult to predict the design costs for any given product (Krishnan and Gupta, 2001). Despite the obvious difficulties in the prediction of cost formation, commonality has been shown to reduce product costs by reducing process complexity and by increasing the economies of scale across the activities in design, production, and inventory processes (Collier, 1981; Fixson, 2007).

Some limitations are important to be considered when designing and using products that involve the component commonality (Jiao and Tseng, 2000; Fixson, 2007). Negative effects that can be observed include lower customer satisfaction, as it may affect service level (Collier, 1982). Not offering exactly what the customer might want in order to gain economies of scale may also lower customer satisfaction (Thomas, 1992). In addition, the use of common parts in products may lower quality in situations, where components are non-optimal for the given product (Fixson, 2007). Over-designing a component may also lead to more costly components if they need to fit the specifications for many different products (Gerchak, Magazine and Gamble, 1988; Ulrich, 1995).

Possible downsides to high component commonality exist (Jiao and Tseng, 2000). Less flexibility in the product line may occur due to high commonality (Collier, 1980). If the company decides to use common components that are non-optimal for any individual product, only for the sole purpose of choosing common components, the outcome may not be optimal (Fixson, 2007). Furthermore, a component may be over-engineered to meet the specifications of multiple designs, resulting in higher component costs (Perera, Nagarur, and Tabucanon, 1999). This phenomenon was described in the study conducted by Ramdas and Randall (Ramdas and Randall, 2008), in which they found evidence suggesting that designing components to be used in multiple different end products, as is common in platform-based design philosophies, can actually reduce the reliability benefits that a new component design often brings. They suggested that the reason for this is the lack of knowledge transfer which is necessary to be able to utilize the experience and know-how gained in manufacturing using the given component. Many times, when there are multiple different products, the products need to be made in different manufacturing locations, easily resulting in inadequate knowledge exchange.

2.4.2 Using component commonality in practice

The possibility to measure commonality gives the company a better opportunity to estimate the benefits and putative drawbacks when making the decisions concerning the design and use of components. In the previous literature, the different ways to measure the component commonality have been addressed (Dogramaci, 1979; Collier, 1981; Wacker and Treleven, 1986; Martin and Ishii, 1997; Siddique, Rosen and Wang, 1998; Jiao and Tseng, 2000; Thevenot and Simpson, 2006; Fixson, 2007). These studies have focused on developing various indices, all of which are measured by different kinds of product data, for example, BOM data (Collier, 1981; Fixson, 2007). The multiple different ways to measure commonality use varying data and give results that need to be interpreted differently depending on which variables/indices are used (Fixson, 2007). For these reasons, the chosen way of calculating commonality may affect the degree to which commonality can be measured as either being advantageous or disadvantageous (Fixson, 2007).

Several different ways can be used when calculating commonality (Dogramaci, 1979; Collier, 1981; Wacker and Treleven, 1986; Martin and Ishii, 1997; Siddique, Rosen and Wang, 1998; Thevenot and Simpson, 2006; Fixson, 2007; Jiao, Simpson and Siddique, 2007). The concept of 'The degree of commonality index' was first described by Collier (Collier, 1981) and this was later defined into further indices such as "Total Constant Commonality Index" (Wacker and Treleven, 1986), "Percent Commonality Index" (Siddique, Rosen and Wang, 1998), "Commonality Index" (Martin and Ishii, 1997) and "Component Part Commonality Index" (Jiao and Tseng, 2000). (Thevenot and Simpson, 2006) The formulas of the commonality indices most prominent for this research are described below. Commonality can be analyzed for a single product or a group of products from BOM data (Collier, 1981). In principle, the commonality indices are different ways of calculating the number of sales items in reflection of distinct component parts.

The first measurement of component standardization was presented by Collier (1981).

The degree of commonality index

$$\mathrm{DCI} = \frac{\sum_{j=i+1}^{i+d} \Phi j}{d}$$

Φj = the number of immediate parent items that contain component j in the set of end items

d = total number of distinct components in the set of end items

i = total number of end items in the set

A component item is an inventory item that goes into higher-level items, including raw materials and purchased sub-assemblies.

The end item is a finished product or a major assembly that a customer can order, or to which a sales forecast can be projected.

A parent item is an inventory item that has components in it (a sub-assembly).

Total constant commonality index

$$\mathrm{TCCI} = 1 - \frac{d-1}{\sum_{j=1}^{d} \Phi j - 1}$$

The TCCI has absolute boundaries from 0 to 1 and thereby provides a better opportunity to also compare products of different families.

2.5 Product life cycle and product portfolio management

Different descriptions of product life cycle can be observed in the literature. The definitions differ depending on what perspective is taken. Crnkovic et al. (2003) define six phases that categorize the product life cycle: the business idea, requirement management, product development, production, operation and maintenance, and disposal as shown in Figure 3. Stark (2016) on the other hand defined the phases as the imagination phase, definition phase, realization phase, usage phase, and dispose phase as shown in Figure 4. The product idea is first imagined, then further defined and realized, and finally used, and after the product is not useful anymore, it gets disposed (Stark, 2016).

Figure 3, Product life cycle (Modified from Crnkovic et al., 2003)

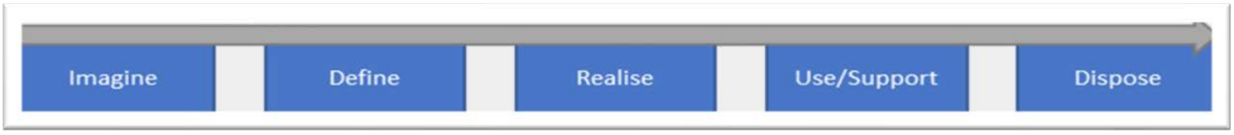

Figure 4, Product life cycle (Modified from Stark, 2016)

Tolonen (2016) specifies another four phases that can be used to describe the product life cycle: the new product development phase, maintain phase, warranty phase, and archive phase as shown in Figure 5. All the activities needed to introduce a new product to the market are contained in the new product development phase. In the maintain phase, new products are sold, delivered, and invoiced. During the warranty phase, after-sales services can be done for the ramped-down products, as well as the sale of spare parts and repairs. The archive phase differentiates from the other descriptions in the sense that the product data is stored. Like in the disposal phases, also in the archive phase no business activity is present. (Tolonen, 2016)

Figure 5, Product life cycle (Modified from Tolonen, 2016)

Product portfolio management emphasizes the choices between markets, products, and technologies (Cooper, Edgett, and Kleinschmidt, 1999). The studies have previously focused on the product portfolio decisions in the new product development phase only, where the prioritization between different product development activities and projects is done. Tolonen et al. (2014) introduced a governance model to deal with the increasing size of product portfolios. The model considers not only the products in the new product development phase, but also introduces the notion of considering the whole life cycle of the products. The model looks into the product structure levels vertically and horizontally and aims to improve the product portfolio decision making by considering the implications of product portfolio explosion throughout all the life cycle phases. (Tolonen, Harkonen and Haapasalo, 2014)

2.6 Synthesis

In any managerial decision, the benefits and drawbacks must be considered. This often, either directly or indirectly, comes down to the monetary impact the decision has. Henceforth, this study is interested if the research could provide some means to estimate the impact of increasing component commonality in a company's portfolio. Even though any quantifiable means to provide estimations could not be achieved via literature, some reference points have been provided in this chapter.

A big product portfolio leads to an even bigger component portfolio. The increasing number of components that needs to be managed is not always considered. This could mean that more RnD resources are used than would be necessary, increasing the cost and prolonging time-to-market. In addition, some of the benefits of component commonality are related to areas beyond design and RnD. The level of usage of common components affects many areas of operations; sourcing, logistics, manufacturing, and after sales services to name some. In all these areas, the component commonality should at least reduce cost and save time.

With fewer distinct components, when the products are in the *maintain* life-cycle phase simultaneously, component costs could be reduced due to larger order quantities. The use of the same components increases the needed amount of a single component, which should serve the purpose of volume benefits in price negotiations with the component vendors. It should also be easier to manage component stock amounts and the money engaged in component stocks: operational costs could be reduced by maintaining smaller (safety) stocks and by reducing procurement activities. Another point, that was not brought up in the literature, is that a smaller number of components could make quality assurance easier, therefore increasing overall product quality and operational quality. For example, in cases, where something should go wrong; it is easier to locate a bug or error (functional or process) when fewer different components are used.

By sharing good experiences and designs between designers, the best and tested solutions can be used in further products. This reduces e.g., the needed design resources, further reducing the development costs and time-to-market. Not only this; sharing of bad experiences reduces wasted design efforts leading to the same benefits. There is a risk that knowledge and experiences are not shared if the products are *manufactured* at different sites.

There are always practical limitations to what level component commonality can be improved in a company's portfolio. Designs need to provide different functionalities and performances, which often change the physical requirements of the designs, making it impossible to utilize common components. In addition to this, the pursue of better, more reliable, and cheaper components lead to there always being new improved component versions available. This should not of course be limited since it hinders the advancement of technology and reduction of component costs. The balance in the level of component commonality versus implementing new designs needs to be found, and it should be aligned with the company's strategy.

The use of common parts in products may also lower quality or increase costs in certain situations. Choosing non-optimal components for products to achieve higher commonality can affect quality. Furthermore, over-engineering parts of a product may lead to more costly components if they need to meet higher specifications of other products. Another important note is that most of the benefits of component commonality are achieved when the products are manufactured in the same time phase. These drawbacks can be mitigated with good knowledge transfer.

While considering the previous, higher component commonality, and hence component standardization, is indeed something that any company should pursue.

3 CASE STUDY – CURRENT STATE ANALYSIS OF THE CASE COMPANY

3.1 Description of the case environment

This research was implemented as a case study for the company *Nokia Solutions and Networks*. Nokia is a multinational telecommunications and information technology company. In this case company, a need to study the possible "re-use" of certain component types had risen. In the company, "re-use" is used as a term to describe what scientific literature defines as 'component commonality'. In scientific literature, 're-use' implies a product design, where the specific components are planned to be re-used after they have served their purpose in the life cycle of the first product. To avoid confusion, the term "re-use" is not used in this study, but instead, we use the term "component commonality". The case company had found interest in standardization and component commonality as it likely brings advantages in a tight competition of the market share. By using this approach, the case company was looking for a new way to improve its current practices. The case company was interested to pursue a study, to reveal how well they are using common components in their products, and to find out where there could be room for improvement.

The case study was commissioned by the department of *Mobile Network*s in Nokia. Mobile Networks provides wireless network infrastructure equipment and services for telecommunications operators. The products include hardware, software, and service elements. This study was done on the hardware elements, which consist of the physical radio stations. Different types of hardware components are used by several RnD designers and other specialists with varying expertise in the designs of the radio stations. The management of the components is done in different processes of the company during the product's life cycle; from RnD all the way up to the production and archive phase. Components are categorized to an even more specific level, but the high-level division used in the company is the following: electronic components and mechanical/electromechanical components.

In the company, a standard component list for electronic components had previously been established. A simple key performance indicator (KPI) is used to compare the components of a product against this list to evaluate new products in the NPD phase. Because the company already had implemented standardization for electronic components management, this research was focused on improving the management of mechanical and electromechanical structures and components.

The company also uses the definitions of “lead” and “variant” to further distinguish the products. The variants, one of which is a lead product, are very similar, but distinct, sales items with small functional differences. The products of the case company are to some extent developed for, and in co-operation with, the customers. The lead product is the one that is developed first, hence most design decisions are made for all products of the program when the lead product is designed. The product data that is used in this research is very crucial for Nokia’s competitiveness and cannot be disclosed to any extent.

3.2 Research method and data collection

3.2.1 Establishing the research questions

This thesis was planned on the main topics defined by the case company. First, the company was looking for the latest scientific knowledge on component commonality and component standardization, that is available in the current literature. For this, a literature review with a synthesis was done. Secondly, information based on the literature review was used to perform a case study. Using qualitative methods, the component commonality of the company’s products was researched, providing a current state analysis. Finally, the results of the product analysis were examined, and observed opportunities to improve component commonality were highlighted from the data. Furthermore, the benefits and drawbacks of those opportunities were then evaluated based on the literature research findings, thus compiling the improvement ideas for the company.

Before the literature review was conducted, the research questions were defined as the following:

1. What are the common themes in component standardization and component commonality management in the scientific literature and how can it be used to the company’s advantage?
2. What is the current state of component commonality in the case company?
3. How could the component commonality be improved in the case company?

The literature review was performed to answer the first research question. The results for this are presented in the ‘Literature review’ section of this thesis. For the second research question, the case study was conducted by using the methods and lessons learned in the literature review. Lastly, the third research question was approached by gathering and compiling the conclusions based on the case study. This was done by reflecting on the learnings from the literature review.

3.2.2 Collecting the current scientific information on component commonality

In the search of the literature sources, several bibliographic databases were used. Source criticism was practiced by choosing scholarly databases when searching for the sources. The used databases were the following: ScienceDirect, JSTOR, Web of Science, and Scopus. In addition, publications on university websites found through Google Scholar were utilized. The following search terms were used independently and in conjunction:

- Component commonality
- Common components
- Component standardization
- Standard components
- Modular products
- Modular production
- Component management
- Product data management
- Product portfolio management
- Commonality index
- Commonality indices
- Product family

The resulting literature sources were promptly assessed by the researcher by reviewing the abstract, and if appealing, then further assessment was done. Most prominent sources were selected for further review based on a few factors. For example, if the source were a case study, the applicability of the field in which the research was conducted was assessed in relation to the case company of this research. Furthermore, the applicability and generality, as well as the practicality of the research findings were examined. Choosing sources from peer-reviewed sources, such as well acknowledged academic journals, was favored. Author criticism was practiced by verifying the author’s relevance in the field, mainly by reviewing his/her previous publications and references in the previously mentioned databases

Following the literature review, the planned case study focused on the company's products, and the current state of component commonality was examined. The lessons learned in the literature review were applied here. Throughout the literature review, a strong theme around measuring component commonality was identified. Based on this, a data-driven approach was taken by analyzing product data instead of the company's processes or practices. Several products of the company were analyzed in the case study using methods found in the literature. A more accurate description of the case study follows in the next chapter.

3.2.3 Data selection

The products for the case study were selected by the case company. Deciding factors were the balance between the novelty of the product and the availability of the product data. The analyzed products included 24 products developed in three different RnD sites located in different geographical areas of Europe, Asia, and North America. The selected products were from six different *programs*. In the case company, a program consists of multiple products that are concurrently developed. The products share the architecture platform and are most often of the same product family, but this is not necessarily the case. For the sake of generalizing for the benefit of this research and practical reasons, a program in the context of component commonality can be thought of as a product family. The chosen products are shown and highlighted in Table 1. All the products were used to familiarize with the used data and to understand the products, but not all were used with the analysis method presented in the results.

Table 1, Analysed products

Older Generation			
RnD site location	North America	Asia	Europe
	Program 1	Program 2	Program 3
	P1V1	**P2L1**	P3V1
	P1V2	P2V1	**P3L1**
	P1V3	P2V2	
	P1V4	P2V3	
	P1V5	P2V5	
	P1L1	P2V6	
	P1V6		
	P1V7		
	P1V8		
Newer Generation			
RnD site location	North America	Asia	Europe
	Program 4	Program 5	Program 6
	P4L1	**P5L1**	P6V1
		P5V1	P6V2
		P5L2	**P6L1**

A somewhat vague division of "older" and "newer" generations will be used between the products. The designs are not all from the same architecture, but the products from different sites share the same life-cycle statuses. The older generation is of the older design, which is still a very new product in the ramp-up phase and the newer generation is a product still in the design phase with just existing prototypes. From the newer generation, only the lead products have BOMs in the release -phase, meaning that there is no data yet to be analyzed from any of the variants, unfortunately. However, the case company desired to involve the newer products in this research, as they most accurately represent the practices and processes that are currently in effect in RnD. The product names used by the company aren't disclosed. The products have been re-named for the purpose of the research with the following logic: Programs have been numbered with a running number, for example, P1 meaning Program 1. The products of the given programs have been named with the respective program number, followed by a letter V or L whether it is a variant or a lead, and a running number. P1L1 means the lead product of Program 1. In Table 1 it can be seen that program 5 has two lead products. The running number doesn't correspond to anything, such as the development status, or chronological order.

Of the products, BOM data was identified as the data necessary for further analysis. In the literature review, several methods to analyze component commonality were identified. A common theme in the previous literature has been to develop an index for measuring of component commonality. For this research, the TCCI was selected as the method to analyze the component commonality in the products of the case company. The reasons for choosing TCCI were the following:

1. this index can be calculated by using only BOM data.

2. as this method provides absolute boundaries, it works better when making comparisons between different product families (in this case *product programs*).

Only two products were selected for all index calculations, the reason being that when calculating the component commonality with TCCI, the index value is affected by the number of products used. Because every program has different amounts of products, only two will be used from each.

3.2.4 Collecting the data

The data collection consisted of accessing the company documents. The company was willing to provide the researcher with bill of materials (BOM) data and pricing data in order to conduct the case study. The researcher was provided with access to company IT systems, and the most up-to-date BOMs were downloaded for the research. Some products were in earlier stages of product development and weren’t available in the PDM systems yet. The BOMs for those products were provided by the program managers on request.

Similarly, as in many previous case studies involving companies in competitive fields, also in this study compromises had to be made when balancing between the benefits of the academic research and the interests of the company. Therefore, there are some data and findings that cannot be disclosed in this Master’s thesis, as they may include crucial information, which – if revealed - could have a negative impact on the Case Company’s competitive position.

3.2.5 Data processing and analysis

The specific way how the products were analyzed using the TCCI was determined by the needs of the company. The case company requested that the researcher approaches the commonality study by focusing on the differences of the products of one RnD site in relation to the others. Therefore, it was studied if better commonality could be observed between products of a single site, in comparison to the commonality between products of two different sites. The hypothesis was that common components could be observed between the products developed at a certain RnD site. However, the component commonality between products developed in separate RnD sites would then be lower. This way it could be determined if commonality is indeed possible to achieve in products of different programs, but is only so in each RnD site, and not company wide. Due to the previous standardization done for electronic components at the company, the difference between electronic component commonality, and mechanical and electromechanical component commonality was studied using the TCCI. The categories of mechanic/electromechanics components and electronic components were deducted from the existing component type classification in the data. The different component types, and the category to which they belong, are presented in Table 2.

In addition, in the mechanical and electromechanical component category, there are also two different types of components that call for different practices in design work and procurement. Catalog components are components that have been designed by the suppliers and are available “on the shelf” from the suppliers. These components are available in the design software, and the designers may use them in their design drawings. Drawing-based mechanics on the other hand are something that the case company’s designers draw themselves when designing the product. The components are then ordered from the suppliers based on those drawings. The drawing-based mechanics can include any sort of component type, but that is not specified in the used data. Based on the supporting analysis done with the company, only catalog components were used in the analysis presented in this work, since it was estimated that improvement opportunities presented for them would be more feasible to implement. All other mechanic/electromechanic component types, except for “drawing based mechanics”, which are presented in Table 2, are catalog components.

Table 2, Component categories and types

Category	Mechanic/electromechanical	Electronic
Type	Label or Sticker, Drawing Based Mechanics, Screw Machine, Connector, Production Material, PWB, Screw Tuning, Nut, Other Mechanical Component, Fastening, Fan or Thermal Part, EMI Shielding, Screw Tapping	Resistor, Capacitor, Inductive Component, Discrete Semiconductor, Protection Device active, Integrated Circuit, Opto Component, Protection Device, Frequency Control, RF MW Circuit

Four different indices were calculated for the products using the TCCI:

1. First, the commonality between the lead product and a variant was calculated for each program, giving an index for how good the commonality is for a given program. This calculation takes into account the mechanical and electromechanical components only.
2. Second, the commonality of mechanical and electromechanical components between the lead products of each separate program was calculated. This gives an index of how high commonality there is between the programs.
3. Third, the same commonality as was calculated for the mechanical and electromechanical components in point 2, will be calculated for the electronic components.
4. Fourth, the commonality of connector components between the programs was calculated.

The calculations were done using Microsoft Excel spreadsheet software (Microsoft® Excel® for Microsoft 365 MSO (Version 2112 Build 16.0.14729.20254) 64-bit**)**. In order to calculate TCCI, the following variables are needed:

Φj = the number of immediate parents that contain component j in the set of end items
d = total number of distinct components in the set of end items
i = total number of end items in the set
A component item is any inventory item, that goes into higher level items, including raw materials and purchased sub-assemblies. The end item is a finished product or a major

assembly, that a customer can order, or to which a sales forecast can be projected. A parent item is an inventory item, that has components in it (a sub-assembly).

To calculate the TCCI of given BOMs, the following actions needed to be done:

1. Only components of the correct categories were selected from the BOM.
2. From those components, a list of only the distinct components was made. This constitutes the variable “d”.
3. For each of those components, the number of parent items containing it needed to be calculated. These constitute the variables “Φj”, and the sum of those is the following $\sum_{j=1}^{d} \Phi j$.
4. With these variables, the TCCI = $1 - \frac{d-1}{\sum_{j=1}^{d} \Phi j - 1}$, could be calculated.

When processing only a few products at a time, these steps are quite easily done manually, by using the data tool “Filter”, and either the command “Unique()”, or data tool “Remove Duplicates”. Excel command “Unique()” actually returns *distinct* values, thereby enabling/providing/achieving the same result as by using the “Remove Duplicates” tool. The final result is the list of distinct components.

However, for such a big number of products, components, and different component categories, manual processing would be very time-consuming. To be able to calculate numerous indices, this procedure would need to be automated. For this, an excel macro was developed. The used excel macro was done in a way, that only the wanted component categories, the number of BOMs, and the BOMs themselves needed to be selected, and the rest was automated. The macro would then open the selected BOMs, copy the components of the selected categories, and list those in the spreadsheet. The spreadsheet would then make a distinct list of those, calculate the variables, and compare the distinct components list to the selected BOMs, giving the TCCI value. The most laborious part of this research was making the excel macro.

From this data, the current state of the component commonality of the company’s products was compiled, thereby providing the answer to research question two in chapter 3.4 Current state synthesis. In paragraph 4 Development ideas, the company’s current state was analyzed based on what was learned in the literature review. There, possible opportunities for improvement in component commonality were highlighted. Furthermore, the benefits and drawbacks of seizing those opportunities were discussed, thus answering research question three.

3.3 Results

3.3.1 The commonality for mechanical and electromechanical components in a single program

The commonality of mechanical and electromechanical components was calculated for every program. For this, in addition to the lead product, one variant product was chosen for the calculation. The number of products considered for the indices was normalized this way because all of the programs did not have multiple variants. The indices for older generation programs are visible in Figure 6, and for newer programs in Figure 7. See Table 4 in the appendix for exact values.

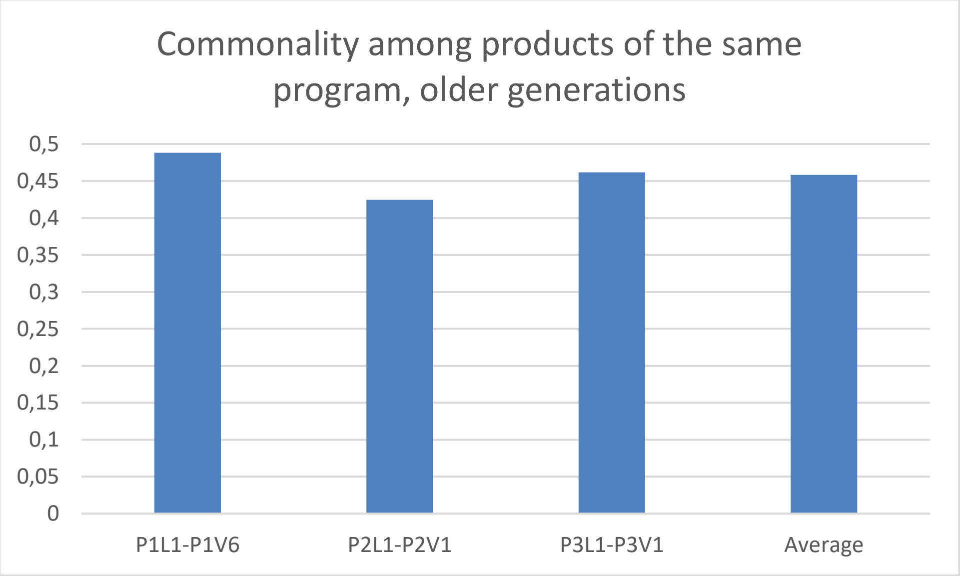

Figure 6, Calculated component commonalities within the older generation product programs. Mechanical and electromechanical components.

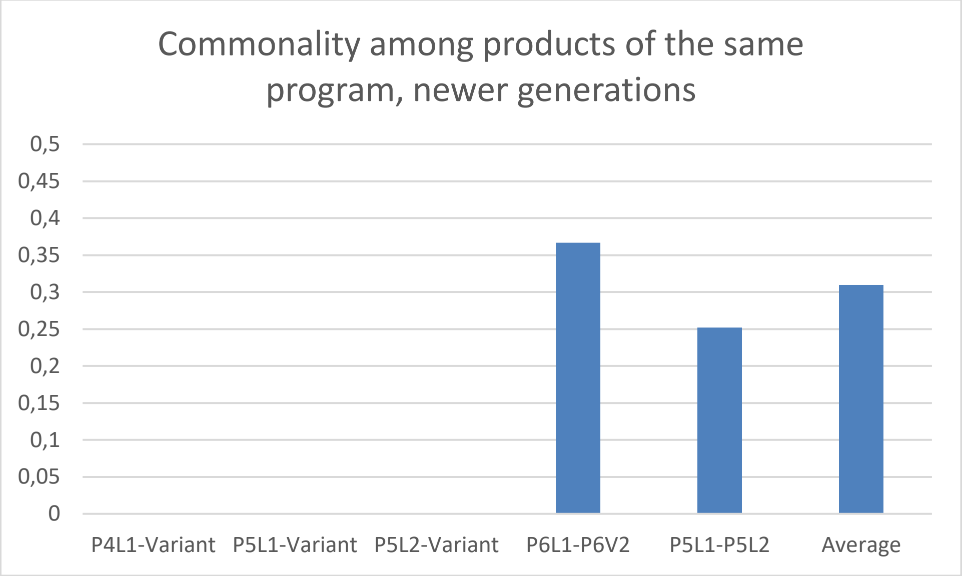

Figure 7, Calculated component commonalities within the newer generation product programs. Mechanical and electromechanical components.

3.3.2 The commonality for mechanical and electromechanical components cross-program

The commonality of mechanical and electromechanical components between different programs was calculated. For this, two lead products of different programs were considered for the indices. The older generation programs were compared to each other in Figure 8, newer generation programs in Figure 9, and finally, the older generation programs of a given RnD site were compared to the newer generation program of the same RnD site in Figure 10. See Table 5 in the appendix for exact values.

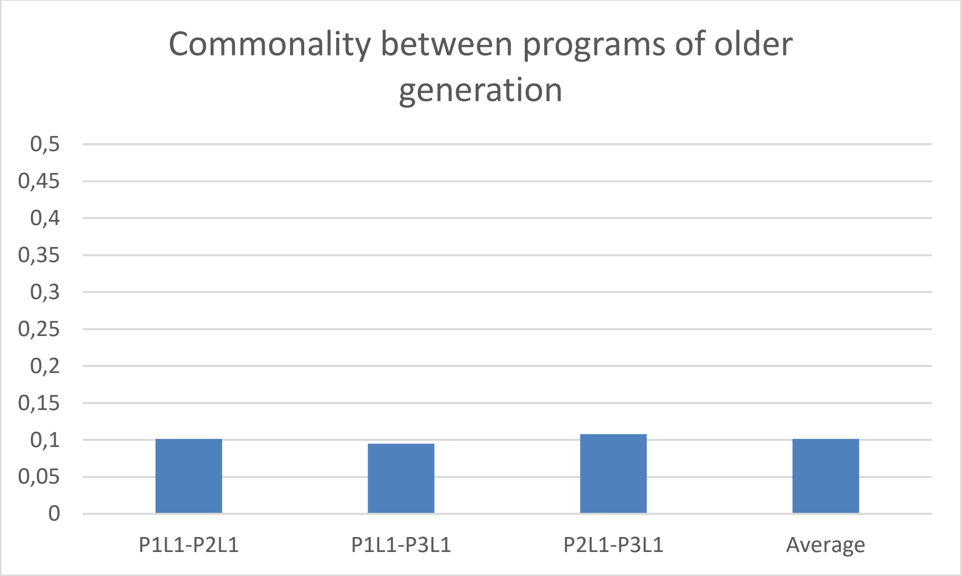

Figure 8, Calculated component commonalities between product programs of older generation. Mechanical and electromechanical components.

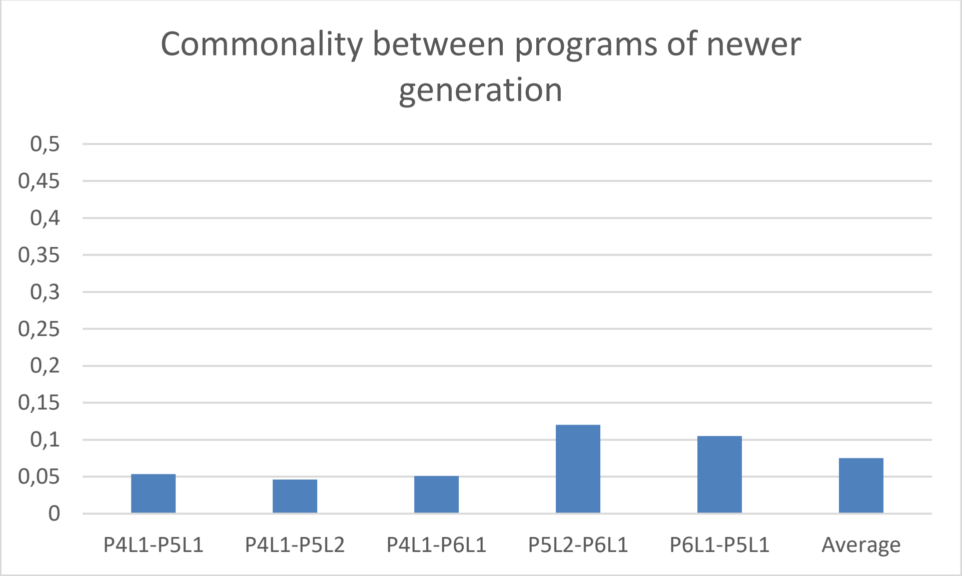

Figure 9, Calculated component commonalities between product programs of newer generation. Mechanical and electromechanical components.

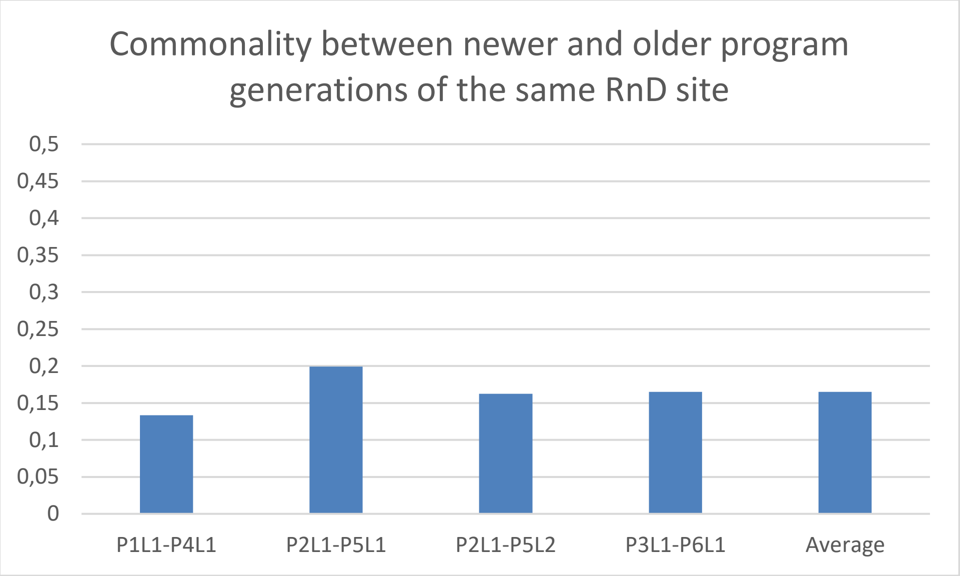

Figure 10, Calculated component commonalities between product programs of newer and older generations of the same RnD site. Mechanical and electromechanical components.

3.3.3 The commonality for electronic components cross-program

The commonality of electronic components between different programs was calculated. For this, two lead products of different programs were considered for the indices. The older generation programs were compared to each other in Figure 11, newer generation programs in Figure 12, and finally, the older generation programs of a given RnD site were compared to the newer generation program of the same RnD site in Figure 13. See Table 6 in the appendix for exact values.

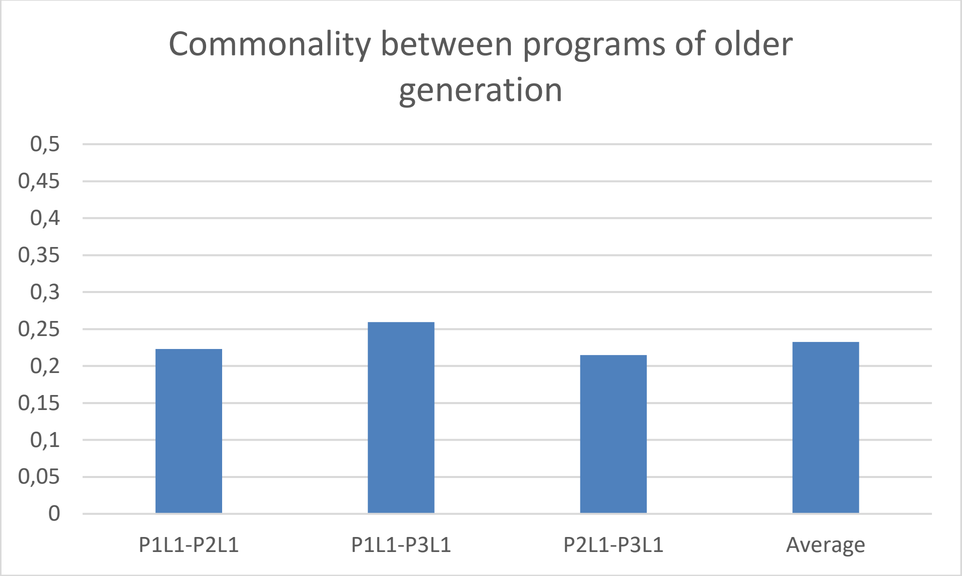

Figure 11, Calculated component commonalities between product programs of older generation. Electronic components.

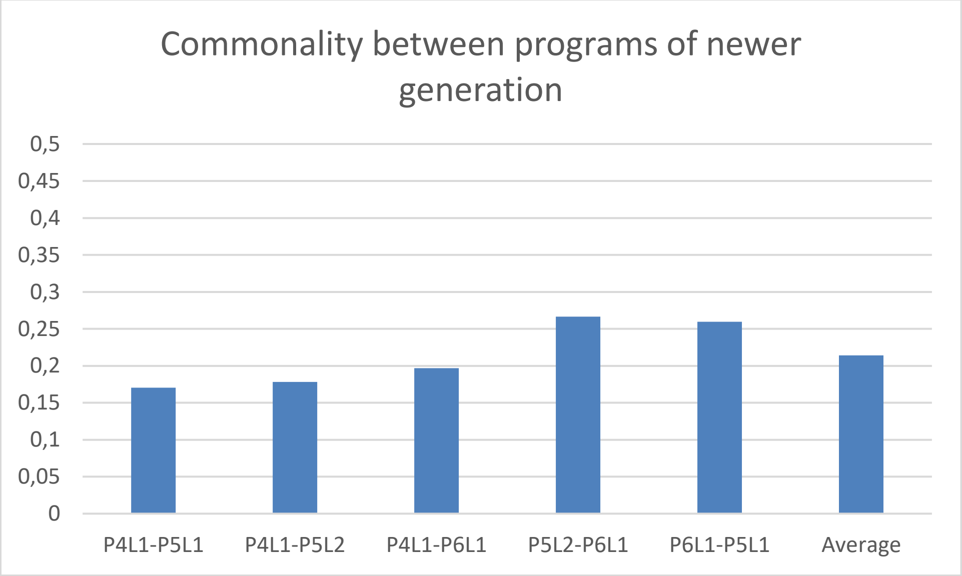

Figure 12, Calculated component commonalities between product programs of newer generation. Electronic components.

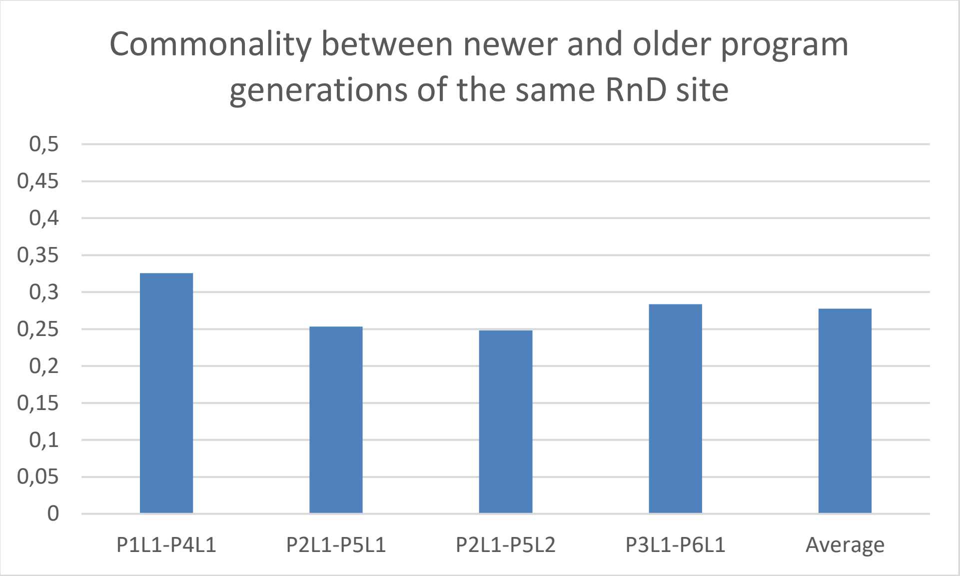

Figure 13, Calculated component commonalities between product programs of newer and older generations of the same RnD site. Electronic components.

3.3.4 The commonality for connector components cross-program

During the research, potential improvement ideas for connector commonality arose. Connectors are electromechanical components that connect the electronic interfaces inside the product, as well as the outgoing connections from the product in the input/output interface. Some previous talks about improving the commonality for these components had taken place across the different RnD sites. Therefore, it was decided that a more precise analysis would be done on this particular component type.

The commonality of connectors between different programs was calculated. For this, two lead products of different programs were considered for the indices. The older generation programs were compared to each other in Figure 14, newer generation programs in Figure 15, and finally, the older generation programs of a given RnD site were compared to the newer generation program of the same RnD site in Figure 16. See Table 7 in the appendix for exact values.

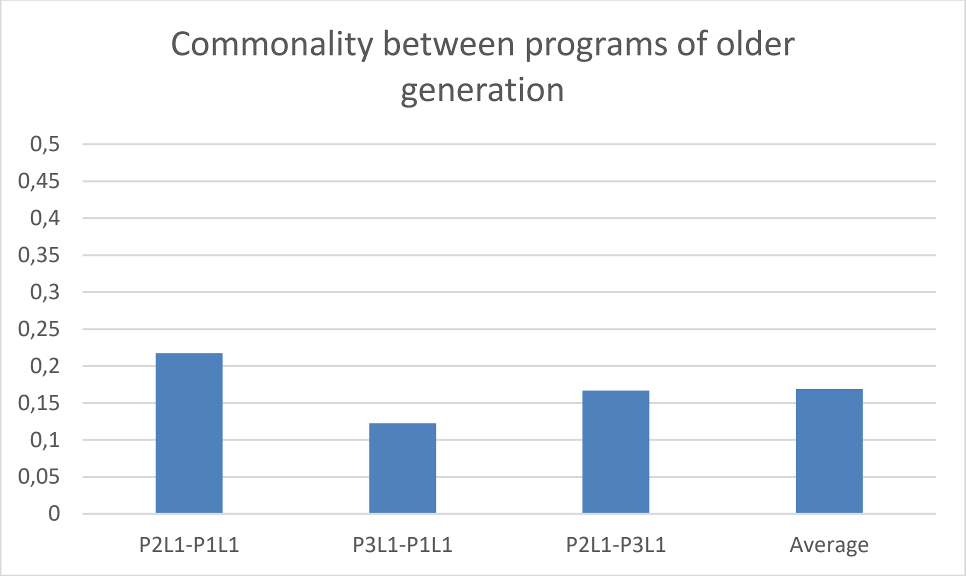

Figure 14, Calculated component commonalities between product programs of older generation. Connector components.

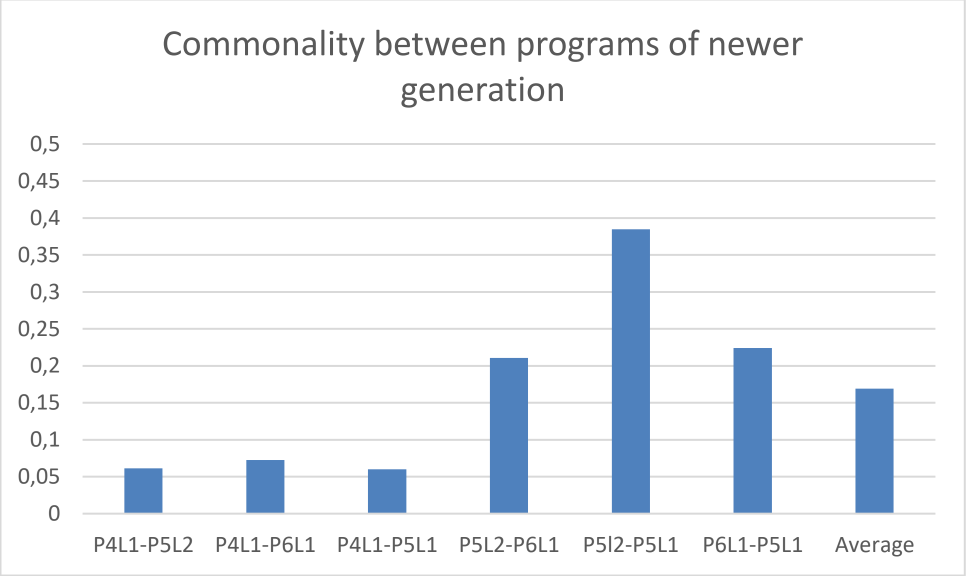

Figure 15, Calculated component commonalities between product programs of newer generation. Connector components.

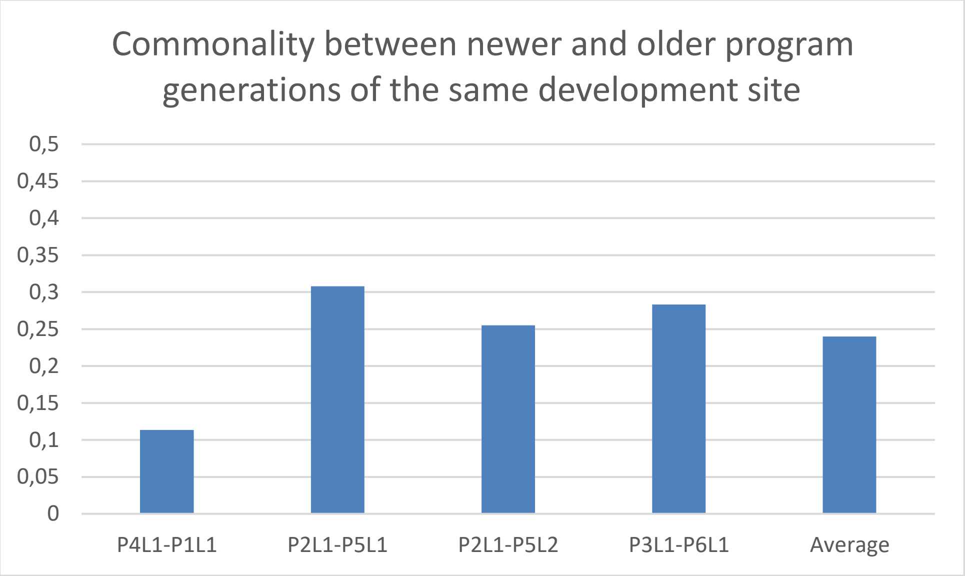

Figure 16, Calculated component commonalities between product programs of newer and older generations of the same RnD site. Connector components.

3.4 Current state synthesis

In this chapter, the results are briefly analyzed. Some reasonings and/or background to the values are provided. The average amount of distinct components in the product BOMs has been presented below in Table 3 in order to provide a better understanding of the products and the results:

Table 3, Average distinct component counts of the products

	Average from all 24 products
All components	475
Mech&eMech components	116
Catalog components	60
Drawing based components	56
Mech&eMech % of the whole BOM	24%

3.4.1 Component commonality within programs

The results reveal that the component commonality within the single programs is very high (Figure 6). This is due to the fact, that the program approach is used when designing the products. The lead product is developed, and concurrently, or following the initial development, the variants with small changes in the product configuration are also developed. This leads to very similar products with the same components. A TCCI value of 0.4-0.5 was observed for the products of the older generations. Here, the results for the newer generations (Figure 7) are not reliable enough for further analysis. This is because their variants are still in the earlier phase of development and there is not yet complete BOM data for them.

To give perspective, a theoretical maximum for the TCCI (100% common components) when calculating for two products with 60 common components, would be 0.504. This is because even though the TCCI has boundaries from 0 to 1, it gives a lower value the higher the component volume is. The difference between 0.45 and 0.5 TCCI is around two components: calculating hypothetical TCCI values between products of 60 components in each, with 58 common ones giving a TCCI value of 0,4522. In comparison, products consisting of 58 components, which all are common among the products, provide a TCCI value of 0,5044. The benefit of the product programs, viewed through the commonality perspective, is apparent: multiple similar, yet different, products can be developed using the same components.

3.4.2 Cross-site component commonality in comparison to component commonality among products designed in single RnD site

One aspect the company was interested to study was the commonality between products of the same RnD site in comparison to the commonality across the products of the whole company. Concluding from the data in chapter 3.3.2, it is evident that the commonality between the products of different sites is undeniably lower in comparison to the products designed on the same site.

The increased commonality among the products of a certain site may be caused by a couple of reasons. The most prominent factor is most likely the personal experience of the designers. It is more likely for a designer to use a design block or component that she/he has already worked on within an earlier product design. Also, mostly similar products are developed at the sites; one RnD site develops products of a certain product family and another one focuses on a different family. It is more likely that those products then have a higher possibility for common component usage due to more close technological specifications of the products. To summarize, the commonality between products of different programs is low, except in those products that have been developed at the same RnD site.

3.4.3 The standardized electronic components

Another aspect that was examined, was comparing the commonality observed for electronic components and that of mechanic/electromechanic components. For electronic components, there already had been standardization practices implemented, which we wanted to examine. One important thing to note, however, is that there are a lot of practical differences in how well a component can be utilized in different designs. This is true for any component type, but even more so when comparing the categories of electronic and mechanic/electromechanic components. Thus, the difference cannot be rationalized as just being caused by the standardization differences. For example, there are not a lot of differences in the making of a 10-ohm resistor (an electronic component). It can be used in any PCB and is easy to be standardized. However, the *technology* used in the products dictates the physical size of the PCBs (electromagnetic wavelength vs antenna length, amount of transceivers, etc.), which further determines the size of the complete product. Because of this, it is often impossible to use the same mechanical/electromechanical components (fe. fans, connectors, casings) in many products. These factors affect the difference in the attainable level of commonality between electronic and mechanical/electromechanical components.

Comparing figures 8, 9, and 10 to figures 11, 12, and 13, we can see that the component commonality for electronic components is significantly higher than it is for mechanical/electromechanical components. Also, the component commonality of products of the same RnD site in comparison to cross-site products isn’t quite as significant for electronic components. Although not certain, this could suggest that the electronic component standardization has indeed worked and has increased the component commonality among the products of the company. A precise comparison would have been possible if commonality was calculated from product BOMs developed before the electronic component standardization. This, however, was outside the scope of this research.

3.4.4 Connector commonality

Connectors were selected as the component type to go through a closer analysis. The same characteristics are present in the data, as were presented for the component categories. It is worth highlighting, that common connectors are found between the product programs of the same RnD site. The data supports the idea that the same connectors can be used across different product programs and platforms.

By examining the connectors on a component level, some solutions using the same components were shown to persist across the products of a single RnD site. In addition, some common components were even identified across the products of different RnD sites. The design efforts of those solutions had not been done in cooperation between the sites. Naturally occurring interest in the work of colleagues had led the designers to familiarize themselves with the work of other RnD sites, but no organized effort to increase collaboration between the sites had been done. Nevertheless, these findings confirm the idea that similar connector solutions and common components could be used across the products of different RnD sites.

4 DEVELOPMENT IDEAS

4.1 Nokia interest

4.1.1 Identifying the development opportunities at Nokia

The case company wanted to know what the current state of the component commonality in their product portfolio was, and if there was room for improvement. The benefits of a smaller component portfolio are evident. Less of managing the components in sourcing and supply chain. Larger order quantities, less time spent designing the products with new components, and increased experience in manufacturing with the already known parts.

Not much was said in the literature about how component commonality could be improved in practice. Nevertheless, it must all start from planting the understanding that component commonality is something to be valued. Since this thesis was commissioned, we can infer that this understanding exists, at least on some level. During the research, it became evident, that component commonality was indeed something that was understood, and thought of, throughout the processes, and on the individual designer level as well. Human nature leads to finding the path of least resistance – which in this case often leads to using familiar building blocks from past products. However, the drive for component commonality was shown to focus on the products of one site only. The development ideas of this research challenge the idea that commonality should be focused on in this site/program scope only.

The challenges arise when considering if it is feasible to improve component commonality in practice and whether it is beneficial or not. With the current practices, the near-perfect commonality is achieved in programs in the case company. Nevertheless, many new components are simply necessary to achieve the intended functionalities of the products, which reduces the component commonality when observing products from different programs. Common components are especially scarce between product programs from different sites. However, the component commonality observed between programs designed at the same RnD site doesn’t suffer as much. The data shows that the use of common components in the products of different designs did not appear impossible. This is proved by the similarities in the designs of the same RnD site:

common components are seen between the older generation and newer generation products. Thus, some possibility for improvement may still exist.

Finding the actual practical examples of improvement opportunities proved difficult. For many of the mechanical/electromechanical components commonality is out of the question for practical reasons and trying to force this current universal truth from seizing to exist would be futile. Still, some further analysis was conducted into different component types on the individual component level with the design experts of the company. This is not discussed more precisely in this thesis paper, but from this examination, the most viable opportunity to improve commonality was determined to be in connectors. This was backed up by the opinions of design experts.

4.1.2 Development opportunity 1: Improving connector commonality

There are some limiting specifications to connectors, mainly physical dimensions, and data rate, but either way, there often are a few different connector suppliers and models available that can achieve the needed results. With some further examination into the matter, it was revealed that the designers of each site have independently been working on similar problems – in some cases resulting in using the same components, and in other cases different ones.

In the case company's scale of manufacturing, even small and quite inexpensive components such as connectors, go through a rigorous process where the most suitable ones are chosen. If this process was communicated on a more companywide level and aimed to select the best connectors for a specific platform (think product family), instead of a program, then significant cost savings could be achieved, if only through larger order quantities only. Independently of this research, a "connector guild" had just been created between the designers of the different RnD sites. It presented itself as the perfect place to improve the co-operation between the sites regarding connectors. The findings of this research were discussed with the guild, and future plans to develop a few types of common connectors were established.

Estimated benefits

A heuristic approach was taken to quantify one aspect of the economics of scale benefits of using common connectors in the case company. A scenario based on past production quantities was simulated, and a business case calculation was done to estimate the possible cost reduction gained from increased order quantities. A selection of three product programs that had been designed and were in production in the same time frame, were selected as a reference. For those products, the realized production quantities and vendor quotes for the components were collected. From that information, the total component expenditure of the connectors throughout the product's life-cycle phase of production was calculated. Furthermore, after a closer analysis of the connectors of the chosen products, some of them were changed into common ones found in the products. Based on the same production quantities and vendor quotes, the new total expenditure for the components was calculated.

4.1.3 Development opportunity 2: Implementing a list of standardized mechanical/electromechanical components

Another possible development opportunity that was discussed with the company was to extend the previously instituted standard electronic component library to include mechanical/electromechanical components. A list of chosen component types to be included in the library was created. The company already had an organizational structure in place, in which the implementation could be managed. However, some problems with the implementation of such a library were discovered. Some needed information transfer between the data systems was lacking, and the library for the mechanic/electromechanics library wouldn't be available to the designer even if created in the PDM system as was done for the electronic component list. Nonetheless, there was already a planned improvement in the pipeline that would fix this issue.

It needs to be highlighted, that such a library may hinder the development of the technology if new improved components aren't taken into consideration when creating new product designs. To mitigate this problem, there should be a procedure that keeps the library updated, and new components could be implemented in it in such a way that makes it more likely that they are used in the new products of other RnD sites also.

4.1.4 Synthesis of component commonality development at Nokia

Ultimately, as evident in the highlighted points above, the higher commonality is achieved through improved cooperation, which requires better information and knowledge transfer. More rigorous design rules and sourcing practices would be necessary in order to increase the use of common components between the RnD sites.

This raises up the even more challenging concept of ‘different sites’. There are different RnD sites, but there are also different manufacturing sites. This matter is not considered further, but one understands that when e.g., there is a need to manage the knowledge transfer between different RnD sites, there is an additional need to manage the knowledge transfer between different manufacturing sites in order to achieve full benefits of component commonality. It would need to be ensured that experiences are also shared with other production facilities – which may or may not co-locate with any of the RnD sites.

Currently, the data systems in place provide imperfect data transfer: the data practices aren’t completely identical throughout the company. This means that a more comprehensive way of increasing component commonality cannot be achieved in the scope of this research. For the connector components, however, a feasible plan to increase commonality was constructed. Better communication through the connector guild will provide the information and knowledge transfer that is needed. Though it is yet another point of contact increasing information overload; developing the connector solutions in cooperation with the other sites through the connector guild should reduce the overall workload of the designers.

4.2 Academic interest

4.2.1 Horizontal portfolio structure and component commonality

One point of interest the researcher had when starting this research was to view the component commonality question through the research done into the horizontal portfolio structure (Lahtinen, Mustonen, and Harkonen, 2019). The effects of component commonality coincide with those of reducing the technical product portfolio size. The product portfolio structure speculation does focus itself more on the higher (portfolio) level decisions often considering a group of products instead of a single product. Nevertheless, inspecting the commonality issue through the portfolio view, was something that would have interested the researcher. Not only how managing component commonality could affect the portfolio size, but how monitoring the portfolio sizes as part of the product portfolio management practices should involve the understanding of component commonality management in addition to the more widespread modularity, product family and platform approaches. However, due to time limitations, it was left out of the scope of this research.

4.2.2 Component commonality – practical benefits

The component commonality literature consists of many different approaches to how commonality is measured. Less focus has been spent on the measurement of the level of effects commonality has. Though these sources do exist, they often are case-specific and not easily generalized. Moreover, very little theory crafting or case studies on how commonality could be improved in practical terms exist. Very often the actual limitations to improving the level of commonality are ignored in the studies.

This research provided one example of a heuristic approach to estimate the effect of improved commonality that is very practical and easy to understand, yet very specific to the case. The existing literature on measuring the effects of component commonality, that weren’t ultimately involved in the context of this research, mostly focus on the benefits of reduced safety stocks. The approach used in this research estimated the cost reduction gained from increased order quantity and could be developed further and generalized in additional research.

4.2.3 Component commonality – portfolio-level approach

In the commonality literature, the component commonality is often regarded as a tool used to examine product families. However, in this research, improvement opportunities were discovered by measuring the commonality across products of different product families and programs. In addition, some of the improvement ideas discussed with the case company of this research included plans to improve component commonality throughout the product portfolio without regarding the product family. However, if scrutinized, the improvements will most likely be confined to the scope of product families (not product programs). This is not because the component commonality improvements were planned in such a way, but because the company uses product families and programs in its development philosophies, which will naturally direct a lot of the focus of component design to the program/family level.

To summarize the previous paragraph: this research challenged the idea that component commonality should be viewed at product family level only. The product family approach, among others means, is used to solve the same issue as component commonality: reducing the internal variety of a company while maintaining the external variety. The size of the product portfolio reflects this variety. The commercial portfolio is often visible to the customer and reflects the external variety, Furthermore, the technical portfolio size reflects the internal variety. Building fundamental practices to increase component commonality throughout a company without confining to the product families could reduce the internal variety on the portfolio level more efficiently.

4.2.4 Commonality, modularity, and standardization

Even though component commonality was examined mostly independently in this research, on a more general level it cannot be discussed without involving modularity and standardization. Modularity has been discussed in great depth not only in component commonality literature but also in product portfolio management, operations management, and design-engineering literature. Like many things, commonality and modularity fulfill the same needs. At some point, “component commonality” and “modularity” are hard to separate. When a component increases in size and complexity, it is easier to regard it as a part or a module, and at some level reaches the definition of a sub-assembly. Often this is also affected by how it is manufactured and by whom. One company’s component may be a sales item of another company, which can include sub-assemblies and components. It could be argued that the difference between commonality and modularity is only characterized by the size of the examined component. As the size of the part increases, then at some point, modularity is used instead of component commonality.

Only a few literature sources even mention “component standardization”. Some sources seem to regard component standardization and component commonality as the same thing, but there are some that separate them. This research would expand on this matter by defining them as two separate things. Component standardization within a company is something that is done on a conscious level. Components are selected using certain specifications to be used in further solutions. The component commonality is something that exists and can be measured. Component commonality can exist by “accident”, but standardization cannot. For example, if by happenstance there are same components in different products of a company, then there is component commonality, but no component standardization. However, if this matter is then noticed, and a conscious decision is made to keep using those same components throughout the products, then standardization can be argued to have taken place. Through standardization practices, component commonality can be increased, though component commonality can be increased by other means also. In addition, when opportunities for commonality are recognized, new component standards can be agreed upon. A more rigorous review of the commonality literature could provide a more comprehensive view of the matter.

5 CONCLUSIONS

5.1 Key results

The research question 2 “What is the current state of component commonality in the case company?” was answered in Chapter 3. Products of the case company were analyzed with the total constant commonality index and compared with each other. The data conveyed that the products designed at the same RnD site had a higher degree of commonality between them than the products of different RnD sites. The higher commonality between the products of one RnD site demonstrates that there must be practical opportunities to improve the component commonality throughout the entire product portfolio.

Answering the research question 3 “How could the component commonality be improved in the case company?” proved to be a bit more difficult. Only a few literature sources discuss the aspect of how feasible increasing component commonality is in practice. This is certainly industry-specific, but practical limitations exist in any kind of product. Even though the data in the current state analysis showed that improvement opportunities should exist, finding them proved to be challenging. Eventually, after a closer analysis of connector components, a feasible opportunity to improve component commonality by developing common connectors was identified.

Another key result of the research was evaluating the impacts of the improvement opportunities. Methods for estimating the benefits of increased commonality were scarce in the literature and either specific in nature, or computationally complex and required a high amount of data. A heuristic method was used in this research to estimate the benefits of increased order quantity gained from increased component commonality. The method consisted of simulating a scenario, in which certain components of given products were chosen to be swapped to a common one. New component quantities for the hypothetical products were calculated based on the realized production quantities. Finally, the new total expenditure was calculated from actual vendor quotes. The calculation showed a notable reduction in the total expenditure of the connector components, supporting the proposal to use common connectors.

5.2 Theoretical contribution

Korhonen et al. (2016) had observed in the current literature the lack of attention to how component commonality can be improved in practice. This became evident in the literature review of this research also. What this research contributes to the previous literature is a pragmatic approach to answering this problem: a chosen commonality index can be used to compare the products of the company to each other. In this research, the products of different sites were compared to each other with the chosen commonality index, and possible areas of improvement were identified. To generalize: if a categorization can be done to the products of a company, then a commonality index can be used to calculate the differences in component commonality between these categories. Any patterns can then be identified using correlational research methods, and opportunities for improving component commonality can thereby be identified.

It is difficult to identify all the cost levels, in which a change in the level of component commonality has effect. This has been identified as a problem in previous literature researches (Perera, Nagarur, and Tabucanon, 1999; Labro, 2004). The findings of this research do line with this observation. No comprehensive method of estimating the cost benefits of component commonality has been identified, and none could be developed in this research either.

However, what this research contributes to the previous literature, is yet another explicit way of estimating the effect of improved commonality. A heuristic method was used in this research, and it appeared to be feasible when estimating the reduced component expenditure by using what-if scenarios based on real-life production quantities and components prices. Though very pragmatic and specific in nature, it does contribute something new to the previous literature. The previous research has mostly focused on the benefits based on inventory reductions and cost drivers (Collier, 1982; Perera, Nagarur, and Tabucanon, 1999; Labro, 2004; Fixson, 2007). What the method used in this research provides is ease-of-use and focus on the economies of scale benefits of the increased order quantities, which have both been lacking in the previous literature.

5.3 Managerial implications

The goal of this research was to analyze the case company's current situation regarding component commonality and to provide recommendations. The managerial implications include the results of this study potentially helping the case company to reduce used resources. Also, other companies experiencing similar issues might be able to obtain ideas to consider component commonality in their operations. The findings should also guide the design teams to increase their cooperation with the other RnD sites in order to develop common components. The feasible opportunities were identified in connector components, thus the newly founded "connector guild", specific to the case company, is the first place where this cooperation should be realized. Other companies might have other suitable bodies, where the co-operation should take place. Large companies have multiple production and RnD sites, and it is desirable to use the strengths of each individual site in certain products. Nevertheless, vertical cooperation between the teams of different sites could be beneficial in order to increase component commonality and decrease used RnD resources. In addition, the cost savings projected in the study should prompt managers to encourage this kind of cooperation even further.

5.4 Validity and reliability

This study aims to analyze the current state of the case company and find improvement opportunities in component commonality. Thus, this research is applied research and pragmatic in nature. It utilizes the existing literature around the subject to find practical solutions for the case company. A quantitative, correlative research method was used in this case study, and the validity and reliability will be evaluated accordingly. Reliability can be defined as consistency (Neuman, 2003). Meaning, that under identical conditions, research conducted by another researcher using the same methodology should provide the same results. Validity, according to Neuman (2003), suggests trustfulness, and measures how well an idea correlates with the real world. Validity is furthermore evaluated using three tests relevant to a case study: construct validity, internal validity, and external validity (Yin, 2009). To summarize, four aspects are taken into account in the critical evaluation of this research:

1. Reliability
2. Construct validity

3. Internal validity
4. External validity

Reliability

In this study, the focus was on the pragmatic side as the researcher was working as a thesis worker for a company. Although a considerable effort was done to examine the earlier scientific literature on the topic, some important aspects may have been missed. As several databases were used while sourcing the literature, the risk of losing important data was minimized. More effort could have been spent on researching the literature on the drawbacks of component commonality and measuring its effects on a more general level, though the previous research on the topics was observed to be minute. Nevertheless, the information and data used in this research were retrieved from peer-reviewed sources and company databases, and it is strongly believed that another research with the same goals would have resulted in similar findings.

In this research, the used calculations were based on well-established and previously validated formulas found in the literature. In addition, they are simple and can be easily understood. To implement the calculations on multiple cases, spreadsheet software was used. Furthermore, to ensure there were no errors in the spreadsheet calculations, some cases were calculated manually and compared to those results. The procedure of implementing the calculations was well presented, which increases repeatability. However, the used product data isn’t publicly available, meaning that the calculations could only be repeated by someone with access to the case company data. If the pragmatic context of this research is kept in mind, then repeatability could be argued to be established, as the party interested in the results has the ability to repeat the calculations. This all contributes positively to the reliability of the research.

Construct validity

To meet construct validity, the implemented study measures need to reflect what is claimed to be studied. A well-established formula from the literature was used in this study, and product data was used to implement the calculations. It can be argued that the selected data presents the study questions well; the studied aspect of common components between the products is directly presented in the product data. Still, alternative formulas for calculating component commonality do exist. However, it was assessed that given the context of this research, no other formula would have fit the studied aspect better, and it is believed that given the simplistic nature of the calculations, similar patterns would have been observed with other formulas as well. In addition, the chain of evidence between the research question, results, and conclusions appear logical and fit the reasoning of the case company experts when they were presented with the findings. Thus, it is believed that construct validity is ensured.

Internal validity

Internal validity refers to whether a causal condition, where event A leads to event B, truly exists. No straightforward causality is claimed in this quantitative research. However, conclusions are made based on the results of the current state analysis. These conclusions were constructed based on the researcher's understanding and ability on the subject matter. This in itself would reduce the validity of the research, but the findings were scrutinized with other members of the academic community, as well as members of the case company, reducing this negative effect.

Another aspect that could affect the validity of the conclusions is the sample size. The sample size of 24 products used in the research is somewhat limited when considering the total amount of products developed by the case company. This number of products was chosen in order to keep the data more approachable and available for heuristic analysis. The limited sample size causes a reduction in validity, as it might cause variability and not cover certain products. However, the obtained results are believed to be valid as they match logical interpretation and the opinions of the experts of the company.

External validity

External validity refers to whether the findings of the research can be generalized beyond the specific context of the study. The whole approach of the research, as well as the used methods and analyses, are very pragmatic and case specific. The empirical data was obtained from a single company's databases, which could mean that the results of this research cannot be generalized. However, it could be argued that other companies in the industry most likely operate similarly, meaning that the same results could be valid in other companies as well. Nevertheless, the results are, if not case company specific, then at least industry specific. This results in low external validity as is common in case studies.

5.5 Future research

One point of interest for the current research was to view the component commonality question through the research done into the horizontal portfolio structure (Lahtinen, Mustonen, and Harkonen, 2019). However, after consideration, it was left out of the scope of this research. The effects of component commonality coincide with those of reducing the technical product portfolio size. A future research interest could focus on building an understanding of whether a component commonality KPI should be constructed to be included on the product management level, or product portfolio level.

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APPENDIX

Table 4, The commonality for mechanical and electromechanical components in a single program

Older generation	TCCI Index
P1L1-P1V6	0,488152
P2L1-P2V1	0,424603
P3L1-P3V1	0,461818
Average	0,458191
Newer generation	TCCI Index
P4L1-Variant	0
P5L1-Variant	0
P5L2-Variant	0
P6L1-P6V2	0,366548
P5L1-P5L2	0,252174
Average	0,309361

Table 5, The commonality for mechanical and electromechanical components cross-program

Older generation	TCCI Index
P1L1-P2L1	0,101322
P1L1-P3L1	0,095041
P2L1-P3L1	0,107692
Average	0,101352
Newer generation	TCCI Index
P4L1-P5L1	0,053571
P4L1-P5L2	0,046083
P4L1-P6L1	0,051064
P5L2-P6L1	0,120332
P6L1-P5L1	0,104839
Average	0,075178
Same site old vs new	TCCI Index
P1L1-P4L1	0,133333
P2L1-P5L1	0,19917
P2L1-P5L2	0,162393
P3L1-P6L1	0,164794
Average	0,164923

Table 6, The commonality for electronic components cross-program

Older generation	TCCI Index
P1L1-P2L1	0,222849
P1L1-P3L1	0,259467
P2L1-P3L1	0,214794
Average	0,23237
Newer generation	TCCI Index
P4L1-P5L1	0,170532
P4L1-P5L2	0,178191
P4L1-P6L1	0,196746
P5L2-P6L1	0,266573
P6L1-P5L1	0,25942
Average	0,214292
Same site old vs new	TCCI Index
P1L1-P4L1	0,325452
P2L1-P5L1	0,253112
P2L1-P5L2	0,247978
P3L1-P6L1	0,283582
Average	0,277531

Table 7, The commonality for connector components cross-program

Older generation	TCCI Index
P2L1-P1L1	0,217391
P3L1-P1L1	0,122449
P2L1-P3L1	0,166667
Average	0,168836
Newer generation	TCCI Index
P4L1-P5L2	0,061224
P4L1-P6L1	0,072727
P4L1-P5L1	0,06
P5L2-P6L1	0,210526
P5l2-P5L1	0,384615
P6L1-P5L1	0,224138
Average	0,168872
Same site old vs new	TCCI Index
P4L1-P1L1	0,113636
P2L1-P5L1	0,307692
P2L1-P5L2	0,254902
P3L1-P6L1	0,283333
Average	0,239891