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Product Complexity Impact on Quality and Delivery Performance

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Abstract

Existing literature on product portfolio complexity is mainly focused on cost related aspects. It is widely acknowledged that an increase in a company's product portfolio will lead to an increase in complexity related costs such as order management, procurement and inventory.

The objective of this article is to examine which other factors that might be affected when a company is expanding its product portfolio, if initiatives are not taken to accommodate this increase. Empirical work carried out in a large international engineering company having a market leader position confirms that cost is increased, but it is not the only factor affected. We can document that there is a tendency towards increasing lead times as well as a drop in on time delivery and quality for newly introduced product variants. This means that the company experiences a reduced ability to deliver on time while also receiving more quality related complaints for the product variants, seldom engineered and produced.

1. Introduction

Increases in variance are important for many reasons. It supports companies in attracting new customers and in creating differentiation from competitors' products. The challenge is to offer the correct variance and how to control the variance. Too little variance will obstruct companies in developing their business, while too much variance will threaten to undermine the efficiency.

When introducing new variants into a product portfolio it will most likely generate an increase in turnover. But it will at the same time lead to an increase in complexity related costs as multiple functions within the company such as development, engineering, production planning, sales and marketing need to deal with more variants. But cost might not be the only factor at stake. When complying with unique customer requests the company will have to initiate an engineering process, for which the lead time and quality of the outcome cannot be determined beforehand.

It will be of significant value to document whether there exists a dependency between an expanding product program and increases in lead time as well as reduced on time delivery and quality, if initiatives are not taken to comply with the increasing product program.

Companies whose main strategic focus is on market share might choose to launch new variants knowing that they will not be profitable, because by doing so they will maintain their market share and create market barriers for new competitors who wish to enter the market. In other words, cost is a price they are willing to pay. But if it can be documented that the lead time and quality are affected by increased complexity the company might need to reconsider. The price of delivering products too late which at the same time fail to meet customer expectations will probably lead to loss of customers and thereby a reduction of market share. It is therefore important that companies consider how to accommodate variance in their product portfolio.

The scope of this article is narrowed to focus on whether there is interdependency between increases in product portfolios and cost, lead time, on time delivery and quality. Later work will then focus on how to accommodate increases in product portfolio.

Data analysis has been carried out in a large international engineering company to investigate whether an expanding product program can lead to longer lead times, poor on time delivery and lower quality. The company is designing one-of-a-kind customer specific products and it is market leader within its industry.

2. Theory

Several theories have relevance for this study, and the most central will be presented shortly below.

2.1 Mass customization

In the world of today's competitive business there is an increasing demand for customized products, driving companies to constantly expand their offered product variety, often with the effect of introducing more complexity into the product families (Pine, 1993). Many companies are thereby experiencing increasing demands from their customers for the delivery of customized products that have almost the same delivery time, price and quality as mass-produced products. (Hvam, Mortensen and Riis, 2008). One way of complying with this is by engaging in mass customization. Mass customization is based on combining the efficiency of mass production with the differentiation possibilities of customization (Tseng and Piller, 2003).

Recent research suggests that in order to achieve full benefits from mass customization a company needs to develop three key capabilities. An ability to identify the product attributes along which the customer needs diverge, an ability to reuse or recombine existing organizational and value chain resources, and an ability to help customers identify or build solutions to their own needs (Salvador, De Holan and Piller, 2009).

2.2 Product architecture and modularization

Many different definitions of a product architecture exists in literature. (Sanchez, 2000) argues that a product architecture is created when a new product design has been decomposed into its functional components and interface descriptions have been fully specified. The types of interfaces range from attachment- , transfer-, control and communication-, spatial-, to environmental interfaces. (Meyer and Lehnerd, 1997) describes the architecture as being the combination of subsystems and interfaces. They argue that every product has an architecture, and that the goal is to make that architecture common across many variants. (Ulrich, 1995) has the comprehension, that a product architecture is the scheme by which the functions of the product is mapped towards the physical components, thus defining the product architecture as the arrangement of functional elements, the mapping from functional elements to physical components and the specification of interfaces among these. (Harlou, 2006) describes a product architecture as a structural description of a product assortment, product family or a product. It consists of design units, standard designs and interfaces, where design units are characterized by being unique to each product, and standard designs characterized by being reused between one or several product families. In this definition a clear emphasis is put on the decision of reuse, adequate documentation and organizational ownership.

Product modularity is closely related to the architecture term as well as mass customization. (Worren, Moore and Cardona, 2002) defines a modular architecture as a special form of product design in which loose coupling is achieved through standardized component interfaces, which enables the production of a large number of end items. In short, product modularity can be defined as the use of standardized and interchangeable components or units that enable configuration of a wide variety of end products (Jacobs, Vickery and Droge, 2007).

2.3 Product complexity

Product complexity describes the variety of and within the products or services you offer your customers. In general too much variety will be a burden both for the customers and the company, while too little variety will decrease the competitive advantage it can be to offer variety. It is often very difficult to find the right level of complexity and many companies suffer from the fear of having too little. Variety in products offering customers something they are willing to pay for is good complexity; variety that they will not pay for, or pay enough for is bad complexity. (Wilson, et al., 2010). Many firms are convinced that they maximize the fit between product offerings and customer desires when they increase their product variety, and that this allows them to maintain or even increase their market share. This might be the case but at the same time companies often experience lower performance of its internal operations when product variety increases (Salvador, Forza and Rungtusanatham, 2002)

When creating variants of an existing product you achieve greater differentiation compared to your competitors. This might result in growth in sales but at the same time it will increase the product portfolio complexity as it is necessary to manage another product variant. It is therefore a balance, and the task of finding an optimal level of product complexity is difficult. The optimal level of complexity in a product portfolio can be described as achieved when the combination of diminishing sales return and increasing costs due to complexity are taken equally into account (Closs, Jacobs, Swink and Webb, 2008).

2.4 Performance Measurement

Performance measurement can be defined as the process of quantifying the efficiency and effectiveness of actions, while a performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action (Neely, Gregory and Platts, 2005).

There are numerous reasons for using performance measurement, but common for all is that individual feelings and perceptions should be replaced with facts. Without performance measures, managers cannot really understand how their business work, the problems within them, and whether their attempts to improve performance is working as planned (Kaydos, 1999). Performance measurement can therefore be seen as an important precondition for making improvements. (Harbour, 1997) even claims that you cannot improve what you cannot or do not measure.

Recent investigations carried out by (Davenport & Harris, 2007) showed that a consistent use of analytics and performance measurement have a great impact on business and financial performance. High performers are 5 times more likely to use analytics strategically compared to low performers.

3. Hypothesis

The hypothesis in this paper is that when expanding the product program it will lead to an increase in cost and lead time as well as a drop in quality for the new variants. The company will then experience a reduced ability to deliver on time while also receiving more complaints related to the new product variants.

Or put differently, companies will experience lower costs, lower lead times, improved ability to deliver on time as well as higher quality for product variants that have been frequently designed.

4. Introduction to Case Company

The research for this article is carried out in a large international engineering company designing one-of-a-kind customer specific products. The company has no physical production but is only designing the products. They are the market leader within their industry and the primary strategic goal is to maintain this position. In order to fulfill this goal the company strives to win every order, even if it requires significant development and engineering work. They thereby also acknowledge that their profit on the short run might be reduced, but it is believed that if the market share is kept high potential competitors will have great difficulties in entering the market, which will secure high profit in the long run. This cannot be substantiated but the company has chosen this strategy and accepted the uncertainty that exists in terms of cost. The objective is then to win every order by delivering customer specific, high quality products on time.

Within the last years the market has gotten more diverse and more unique customer requests occur. This is reflected in the product program, which today is approximately twice the size as it was just 5 years ago. This has resulted in an increased pressure on the engineering departments as they are required to design considerable more new variants than earlier. The consequence has been a steep increase in the number of very customer specific product variants in the product program. Sales statistics show that more than 40 % of the product variants sold to the market has only been designed once or twice within the last decade. Nevertheless, the company strategy of complying with every customer request no matter how unique remains the same.

It is a characteristic for the company that the sales department is quite decoupled from the engineering departments. The sales department is counseling and negotiating contracts with potential customers without showing too much consideration for potential engineering constraints and challenges. As mentioned above the company strives to win every order, regardless of how unique the request is from the customer. The belief is that the best way to satisfy the customer is to offer the most technically advanced solution or to comply with the customer’s request without trying to sway the customers towards choosing a product variant that is more frequently designed. The company fears that if an alternative variant is suggested to the customer, the customer will instead address a competitor and place the order there.

At current time the customer is therefore not consistently informed of how unique the variant being requested is, and how often it is actually designed. The uncertainties that might exist concerning development time and level of quality for new product variants are therefore not known by the customer. This means that the customer ordering a unique product variant is not given the opportunity of reconsidering whether another frequently designed variant should be selected instead.

The company is using a modular based product platform. When introducing a new variant it doesn’t necessarily mean that all modules are new. On the other hand, two variants with the same designation are not completely alike either, as the products are specified in accordance with specific customer requests. Two customers asking for the same product might have different preferences requiring modification of the original design, thus resulting in design of new modules. When a substantial amount of orders has been made for a specific product there is a larger basis for reuse of modules for the specific product variant. So the more often a variant has been designed, the less new modules are needed in average to fulfill a new customer request. The modules differ significantly in size as well as the corresponding workload required for designing it. This analysis takes into account which new modules are designed for each specific order.

5. Definition of Measurements

In order to illuminate the hypothesis stated above, analysis has been carried out for following six measures:

5.1 Number of design specifications made according to each product variant

A design specification is a complete design of a product variant each consisting of approximately 100-200 modules depending on which product variant is chosen. Two instances of the same product variant can have the same designation without all the modules are the same. But the functional properties remain the same and that is why the same designation is used. There are today 158 different active product variants in the product program. An active variant here signifies that a specific design of the variant has been made within the last decade. The measure will illustrate the diversity in the company's product program according to how many variants are offered to the market as well as how often each of these variants are actually designed.

5.2 Average % new modules made per design specification according to each product variant

As mentioned above, a design specification consists of 100-200 modules. This measure tells in average how many of these modules are new in the design specification according to each product variant. The remaining modules are then reused from earlier design specifications.

5.3 Average costs associated with designing new design specifications according to each product variant

The costs associated with designing a new design specification is dependent on the number of new modules that need to be designed. But the kind of modules that need to be designed also have great influence on the costs. This measure tells the average cost of working out design specifications according to each product variant.

5.4 Average on time delivery of modules according to each product variant

The modules in each design specification are delivered successively and there are different delivery deadlines for the different modules in each design specification. The measure reports how many modules in average are not delivered on time according to each product variant.

5.5 Average lead time for new design specifications according to each product variant

The lead time is here defined as the amount of engineering and development time that goes into designing the new modules needed for each design specification. The measure is dependent on how many new modules that need to be designed for the design specification as well which types of new modules are required. The lead time for designing new modules is then grouped according to which product variant they are intended for. The measure therefore tells us the average lead time for making a complete design specification according to each product variant.

5.6 Average complaint related costs according to each product variant

This measure is chosen as indicator for the quality of the designs made. The more complaint related costs that occur for a specific design specification the lower quality is the design specification assumed to have. The measure reports the average complaint related costs that occur per design specification according to each product variant.

The approach for testing the hypothesis is now to relate the first measure, '*Number of design specifications made according to each product variant*', according to the remaining five measures. It can thereby be tested whether it can be rendered probable that lower costs, lower lead time, improved ability to comply with delivery deadlines and higher quality occur for product variants, that have been designed frequently compared to the rarely designed product variants.

6. Research method

The data upon which the findings are based is drawn from the company's PLM and ERP systems as well as internal company databases. The findings are therefore mainly quantitatively based. Some sources have existed for many years and contain data that has been registered elaborately for more than a decade. But other sources have not been established until 3 years ago. It has therefore not been possible to acquire data that could describe every single product variant with regards to all six parameters under investigation for a period of 10 years. This especially becomes evident when considering product variants that are rarely designed. If one design has been made only a few times within the last decade, it has in some cases not been possible to identify data describing the same variant in terms of for example on-time delivery. But nevertheless each finding is based on a significant amount of data including approximately 2.500 complete design specifications each including a set of modules, more than 45.000 newly designed modules and close to 7.500 complaints.

A clear limitation for this article is that only data for one company has been analyzed. It is therefore only possible to investigate whether the hypothesis can be substantiated for the case company. In order to generically test the hypothesis, similar data analysis should be carried out in several other companies.

7. Empirical data

As mentioned above the data for this research is drawn from several systems. This paragraph will elaborate on the data foundation for each of the six measures used. The number of design specifications as well as the number of new modules made per design specification according to each product variant is based on data from the company PLM-system. For every module delivered to customers it is checked whether the module has figured in earlier design specifications. If not, the module is assumed to be a new module.

The costs associated with design according to each variant are based on expenses registered as design costs from the company ERP-system. Each design department has declared their resource consumption for each design task. By grouping the design costs associated with each specific design specification across all departments, it has been possible to estimate the average costs associated with working out new design specifications according to each product variant.

On time delivery of modules is based on internal task management databases containing customer expectations concerning lead times for different modules. This data is cross referenced with PLM-data stating when a design specification has been created and when the different modules are actually sent to the customers. The module is assumed to have been delivered on time, if the period between the creation of the design specification and the delivery date of the modules within the specification is shorter than stated in the task management databases.

The average lead time for new design specifications according to each product variant is also based on PLM-data. Lead time for all modules has been registered as the period between the creation and the release time of the module. For each design specification it is then summed up what the total lead time is for all new modules figuring in the relevant design.

The final measure, complaint related costs according to each product variant, is based on expenses registered in the ERP-system by warranty and maintenance employees in the company.

8. Analysis

Based on the data gathered it is possible to test the hypothesis of the article.

Each of the following plots has the same horizontal axis as well as primary vertical axis, to the left, designated ‘Designs made’. Along the horizontal axis, each product variant is shown arranged after how often the specific variant has been redesigned, with the most frequent furthest to the left. Along the primary vertical axis is then the actual number of redesigns illustrated by the blue columns for each product variant.

The plots then differ with respect to the secondary vertical axis, to the right, where the following five parameters are outlined; average cost per design, average number of new modules per design, % of modules not delivered on-time, average lead time per design and average complaint related cost per design. For each parameter a linear tendency line is depicted in accordance with simple linear regression. These tendency lines will give indications of whether the hypothesis can be substantiated.

Most numbers along the secondary axes have been indexed of confidentially reasons.

Finding 1 basically shows the relation between how often a product variant is designed and what the average cost of designing the variant is. As an example of how to read the plots consider product variant 61, marked with a circle. It has been redesigned 7 times, which can be read from the primary vertical axis to the left, and the cost index is approximately 60, as indicated on the secondary vertical axis to the right. As expected, there is a tendency stating that product variants that are rarely designed are more expensive to design.

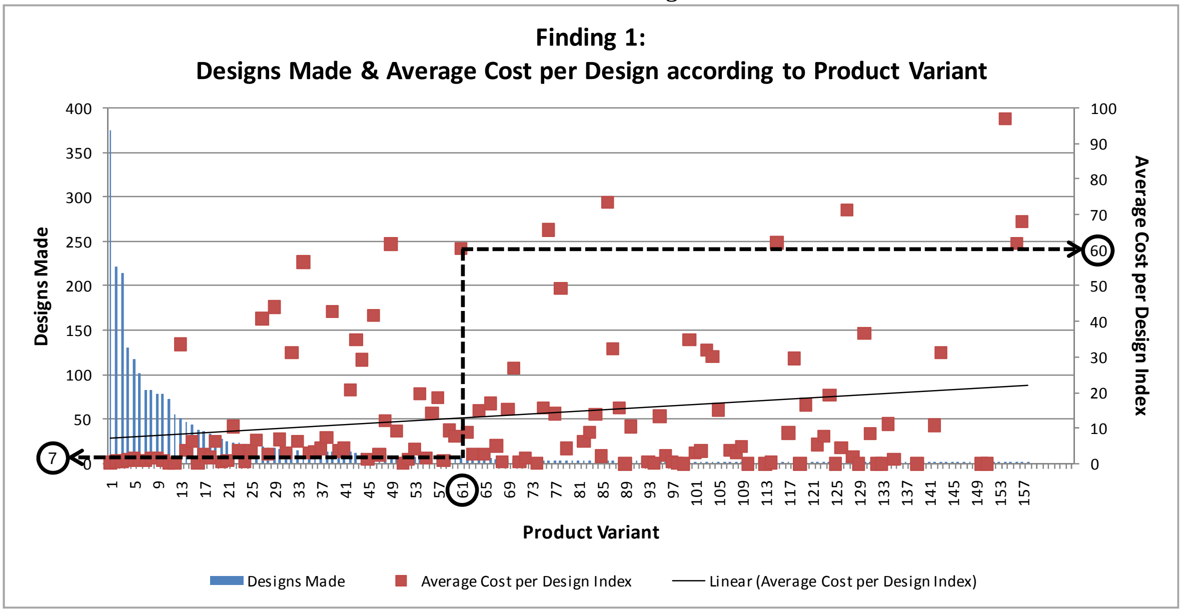

Figure 1: Designs made and average cost per design according to product variant

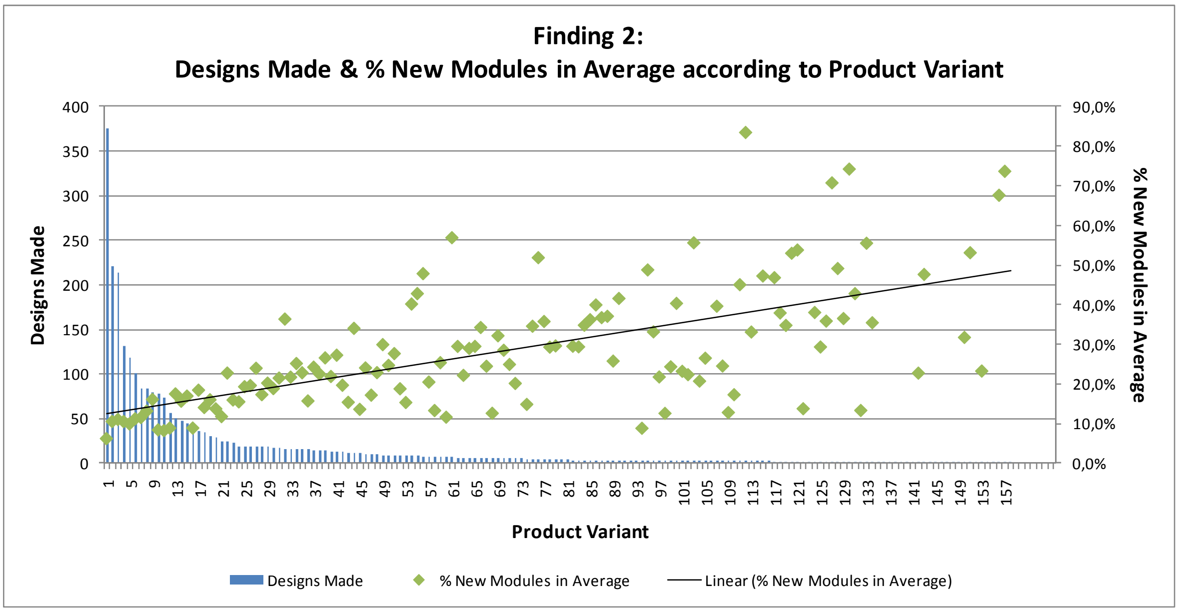

Figure 2: Designs made and % new modules in average according to product variant

Finding 2 illustrates how many new modules that in average are made each time a product variant is designed. It therefore states how good the company is to reuse modules for every product variant. As expected, only few new modules are required for product variants that are often designed. The tendency is very clear and it is worth noticing that the dispersion of data is bigger for rarely designed variants. This indicates that the uncertainty concerning how much design work that needs to be put into designing a product variant is greater for the infrequent variants.

Finding 3 is showing the relationship between how often a variant has been designed and how many modules fail to meet the intended delivery deadline for each variant. The data is somewhat scattered but there is a tendency towards reduced ability to deliver modules on time for product variants that are rarely designed. As the data for the company's ability to deliver on time has only been registered for 3 years there are some holes in the empirical foundation. It would be very interesting to repeat this analysis when more data has been gathered to see if the tendency will continue. Nevertheless finding 3 shows a quite clear tendency and it can be rendered probable that the ability to deliver on time is improved the more often a product variant has been designed which supports the hypothesis.

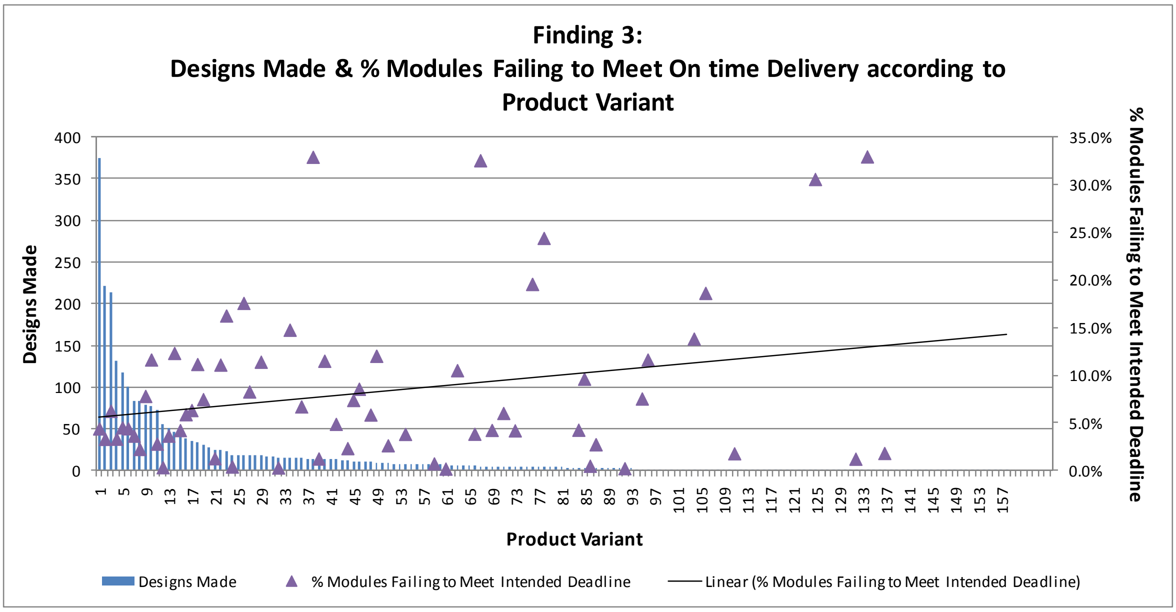

Figure 3: Designs made and % modules failing to meet intended deadline according to product variant

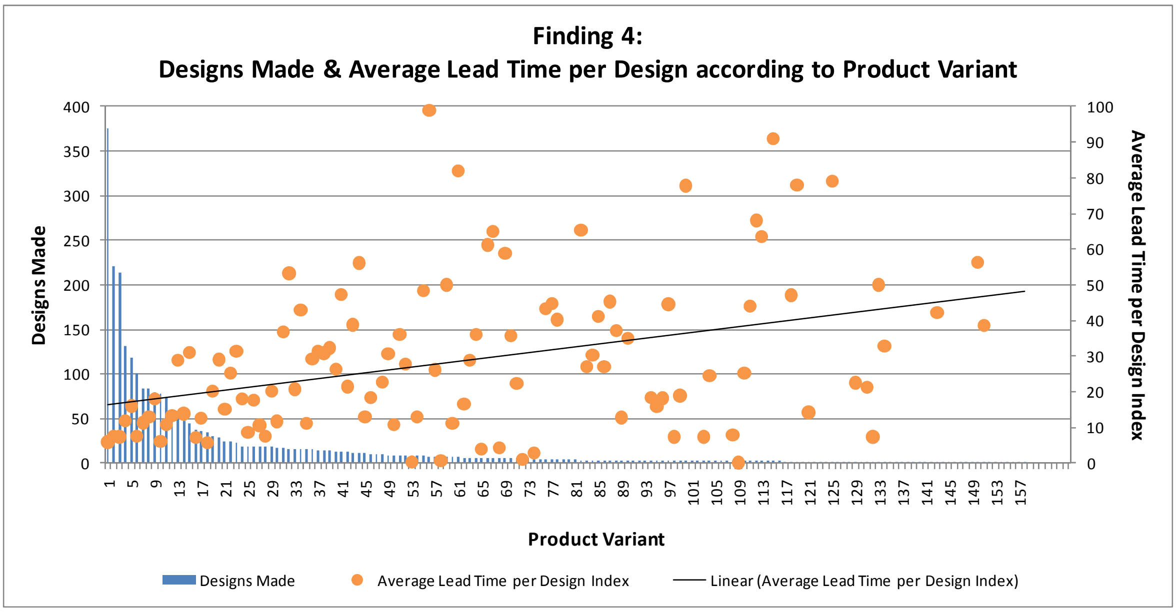

Figure 4: Designs made and average lead time per design according to product variant

By combining the data foundation for finding 2 and 3 it becomes evident that there is a clear connection between the two. Analysis concerning on time delivery for new modules shows that 47 % of the modules are not delivered on time, whereas modules that have been used before only fail to meet intended delivery in 16 % of the cases. The customer ordering a unique or rarely designed product variant will therefore have a considerably different perception of the company's reliability compared to the customer ordering a frequently designed product variant. The reason for this deviation is that at current time the number of new modules needed for a specific order is not taken into account when determining delivery agreements. This is an undesirable situation and the company might need to reconsider their procedures on this matter.

Finding 4 addresses the lead time according to each product variant. Again a rather clear tendency can be spotted indicating that product variants that are rarely designed have a significantly longer lead time compared to frequently designed variants. The reason for this can be found by again referring to finding 2 showing the amount of new modules needed for each product variant. Data analysis shows that for approximately 86 % of the module types, new modules have a longer lead time compared to reused modules. Thus, ordering a rare product variant leads to a larger requirement for new modules which again leads to a longer lead time.

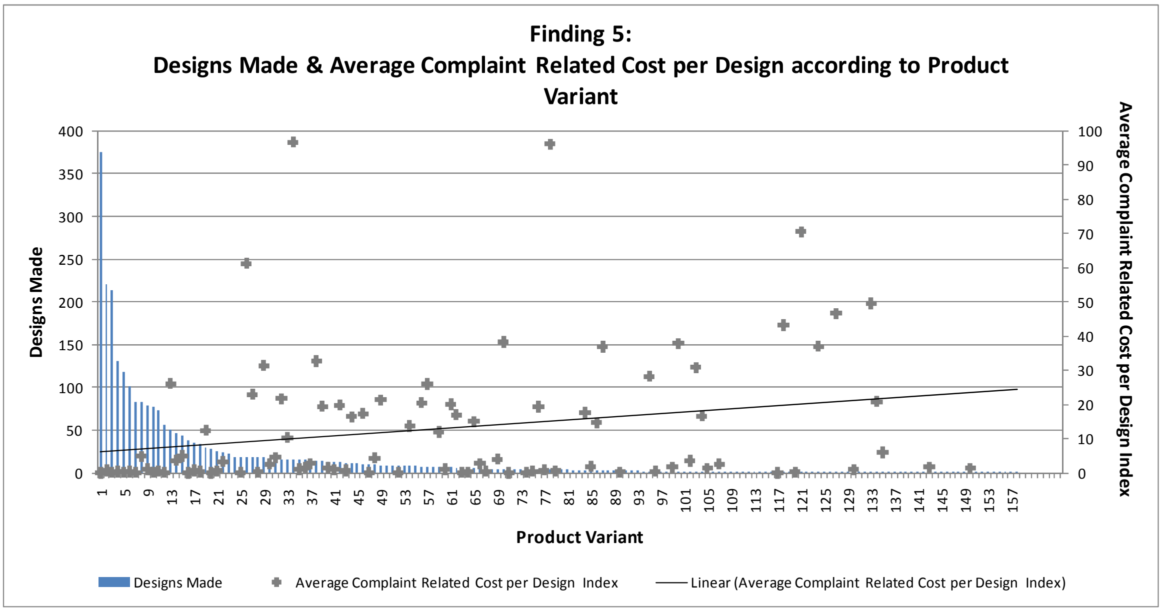

Figure 5: Designs made and average complaint related cost per design according to product variant

This means that the customer ordering a more unique variant will experience a considerable later time of delivery. As it was noted earlier the delivery agreements are by default not influenced by which variant the customer is ordering. Therefore a customer will most likely have the same expectation concerning delivery time every time he or she is ordering a new product. But as finding 4 shows, the lead time differs from variant to variant, and the customer might experience ordering a product and then receive it significantly later compared to the last product ordered. This is unfortunate and will undoubtedly affect the customer's perception of the company's reliability in a negative direction.

The hypothesis is thereby supported as lead time is higher for product variants rarely designed.

The final finding addresses the complaint related costs according to each product variant. Again the hypothesis is substantiated as the gathered data shows a tendency towards increased complaint related costs for product variants that are rarely designed. For these variants the company will experience increased costs in rectifying errors in the design while at the same time the customer will lose confidence in the company.

All in all the plots show the same tendency. Product variants that are rarely designed are likely to be more expensive to design, to require more new modules, to have a longer lead time, to exhibit a more frequent failure to meet delivery deadlines and to result in increased complaint related costs.

9. Conclusion

Based on the findings the initial hypothesis can be substantiated. It is found that there are tendencies showing that the more often a product variant is designed the lower is the cost and lead time for designing it, the ability to deliver on time is improved and the complaint related cost for the given product variant is lower.

As the situation is today the company strives to win every order by designing exactly the product the customer is requesting delivered on time and in highest quality. But finding 3-5 reveals that they are not completely successful in doing so. The belief is that by complying with every unique customer request the company will get the most satisfied customers. But if the customer experience a longer lead time and a poorer quality, the customer is unlikely to be completely satisfied.

The company's main objective of maintaining or expanding the market share is understandable. But the company should be careful that they in their pursuit of fulfilling every unique customer request, do not undermine the very same thing they are trying to achieve. They should therefore consider distinguishing between product variants that can be regarded as standard products and variants which are more unique. When customers then order product variants that are rarely designed the company can still choose to accept the order. But before doing so, they can inform the customer of the consequences, in terms of lead time and quality that are likely to occur. If the customer has been presented to these issues up front, the level of dissatisfaction occurring if modules are delivered late and are in inadequate quality, is likely to be considerably lower. Another scenario could be that the customer decides to choose a different more common product variant, if lead time and quality is of highest importance. This will also be beneficial for the company as the cost of designing these frequently occurring variants are shown to be lower.

As mentioned earlier there are many product variants that have only been designed once or twice within the last decade. A potential error in this research is that characteristics for the period in which the design is made, is not taken into consideration. One design might have been made at a time where the overall workload in the company has been very high. A long lead time will then not necessarily mean that a lot of working hours has been put into designing the variant. It could just be an expression of general bustle where many orders are processed at the same time.

A clear limitation of this article is that the findings are based on data from one company only. It can therefore not be concluded whether the findings can be generalized. The plan is to expand the study to include at least five more comparable companies to test the hypothesis on a wider scale. If similar tendencies can be found, the validity of the findings will be improved considerably. Another aim of the future work will also be to get insight into how engineering companies could actually deal with increases in their product programs. Are they aware of the consequences and how do they try to minimize the undesirable outcomes? Three dimensions will then be evident to address; people, processes and tools. Could the solution be to simply hire more people? Or should processes be improved to better comply with the increasing portfolio? Would it for example be suitable for companies to divide their design processes into at least two main tracks? One track to take care of the standard requests and typical design work and another track dealing with very customer specific and unprecedented requests. Or would it be better to apply new tools and technology to assist the companies in accommodating and controlling the increasing variance? And how are the opportunities for combining these? These are all questions that are highly relevant, and which will be addressed in our future research.

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