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# Future Alternatives for Automotive Configuration Management

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**Abstract**

This research investigates the phenomenon of increasing cost that results from growing product complexity. To explore this phenomenon, interviews with ten senior managers and engineers with long experience in the automotive business were conducted at a car manufacturer. The interviewees agreed that configuring cars becomes more time-consuming and costly with increasing product complexity. In this paper we reason that there are upcoming solutions suitable for complex configurations. As a basis for this, we propose a distinction between limiting and managing product complexity, and stress that these approaches affect internal cost over time differently. If companies choose to limit complexity we suggest optimizing configuration rules, reducing variants or both. Conversely, we propose and contrast two different configuration strategies for managing complexity, 1) the Modular approach, and 2) the Configurable Component (CC) approach. The Modular approach may limit the ability to change. However, only few changes in manufacturing systems are needed. The CC approach is a long-term fully flexible configuration approach prepared for changes. As a drawback, the CC approach may involve high fixed costs due to the need for suitable manufacturing systems. We conclude that both the Modular approach and the CC approach are feasible for managing complexity. In a long-term perspective, it might be necessary to be able to prepare for change and reduce internal cost over time. The choice of limiting or managing complexity might therefore be a demarcation of future competitiveness.


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*Keywords:* Configuration ; Product Complexity ; Internal Cost ; Modular Platform ; Flexible Product Architecture

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## 1. Introduction

The traditional research on platforms and component reuse often focuses on economies of scale for manufacturers of consumer goods in the production phase[1]. In the beginning of the 20th century Ford's mass production system dictated that identical products should be produced over and over again to reduce overall cost of manufacturing. Prices went down, the mass-producing companies became successful by offering mass-produced goods, and workers' salaries went up. However, in this paradigm companies discovered a market for customized products, which they targeted with niche products for specific customer needs. These customers were prepared to pay a premium for a customized product. What we can see now is upcoming enablers, both in manufacturing and design, to further integrate design, configuration and manufacturing processes. Advanced manufacturing systems and configurable products let companies benefit from a low-cost production in a long-term perspective while being able to offer personalized products.

### *1.1. Product Architecture in the Automotive Industry*

In recent decades, car manufacturers have increased investments into product development and manufacturing processes in order to reduce internal cost[2]. In this way, companies also address issues concerning the product architecture and how to adapt when customer needs change over time. Widely defined, product architecture is "*the scheme by which the function of a product is allocated to physical components*"[3]. In these terms, a product's architecture is intended to carry benefits such as commonality across product variants whilst each individual variant is perceived as distinct by the customer[4].

Product complexity is increasing. This complexity is typically addressed by implementing a platform strategy to either serve several products or brands (in time) or to prolong the product's lifecycle and make it upgradeable or suitable for face-lifts in the future (over time). A platform strategy may be introduced to increase the reuse of components between products and the reuse of processes, as for managing internal cost[5]. Therefore, a product's architecture defines the essential economies of a product, while it extensively may affect company results[6].

### *1.2. Configuring Products within and outside the Platform's Design Boundary*

In addition to the definition above, a platform may also be defined as "*a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced*"[7]. Thus, a platform can be the basis for a range of products that are configurable within a specified design bandwidth, manufactured and available for customers over a given range of time. However, while customer needs evolve, the tangible platform may become out-dated, forcing the development of products outside the design boundary of the platform. The design bandwidth can, in this context, be described as the platform's feasibility in different products within a given variation in design[8]. An illustration of an arbitrary design bandwidth is shown in Fig. 1.


Fig. 1. Illustration of an arbitrary bandwidth of a platform, where a number of product variants can be found within and outside a platform's design boundary.

Products based on a platform that are forced out of their intended design boundary may be stuck with an unmanageable complexity. This complexity typically derives from a narrow defined, and planned for, platform, or may occur when products (within the platform design boundary) need to be altered (outside the platform design boundary). Therefore may products based on a platform that are forced out of their intended design boundary instigate increased engineering cost[2] and loss of intended economies of scale[9]. Thus, the benefits of the platform strategy lose their purpose. This puts pressure on the definition of the design bandwidth of the platform, and how this boundary is managed to better meet future customer needs.

### *1.3. Need for a Flexible Product Architecture*

There is a general belief that by offering many product variants, a company will gain equally many individually satisfied customers. However, it can be argued that this rather depends on the company's market segmentation and its ability to adopt market changes. Several internal company challenges related to these changes can be recognized[10]:

- Increasing frequency in the introduction of new products
- Large fluctuations in product demand and mix
- Design changes in parts of existing products
- Changes in government regulations
- Changes in process technology

Globalization as well as unexpected and frequent market changes drives the need for a flexible product architecture. In light of these market changes, companies can adopt and mix different strategies: exclude a changing market, plan for change, and increase responsiveness to change[11]. It is thoroughly argued that a precocious product architecture plan is critical for platform-based products, yet such a plan is seldom developed[2].

## 2. Research Approach

In this paper we will elaborate on the current practice in the automotive industry and propose more flexible configuration principles that involve options based on early design parameters. Today, configuration is described in an "include" or "not include" fashion, where real value-adding options are seldom available. For example, it is impossible to order a car from standard car manufacturers with additional legroom or with a slight change of the doorframe, to fit individuals better.

We will mainly contrast two concepts, the Modular approach and the Configurable Component (CC) approach. The timeframe given for implementation of the suggested approaches is 3 to 20 years, which gives us as researchers the opportunity to explore controversial alternatives that are beyond the traditional continuous improvement cycle of the product architecture and its support systems. We will also delimit us from normal change management and legacy issues of the state of practice.

### *2.1. Research Question*

A premium product segment is a long-term business strategy, or even a company vision. This is a strategy where the existing platform definition is extended to fit configurations including premium standard products or premium customized products. We believe that by investigating the current state in the automotive business, we will be able to distinguish the difference between limiting and managing product complexity, and the main consequences and possible choices related to these concepts. This paper is hence driven by the following research question:

*How can car manufacturers configure premium cars more flexibly to meet customer needs while limiting or managing complexity and cost?*

### 2.2. Research Objectives

An industrialized product architecture aimed for standard product segmentation implies a relationship between cost and the level of customization as exponentially increasing (see Fig. 2a). The current paradigm dictates that a standard product equals low internal cost, while a highly customized product typically equals high internal cost. Although, we forecast a paradigm shift where new technology and processes in manufacturing systems will be suitable for producing premium customized products with the benefit of economies of scale (see Fig. 2b).

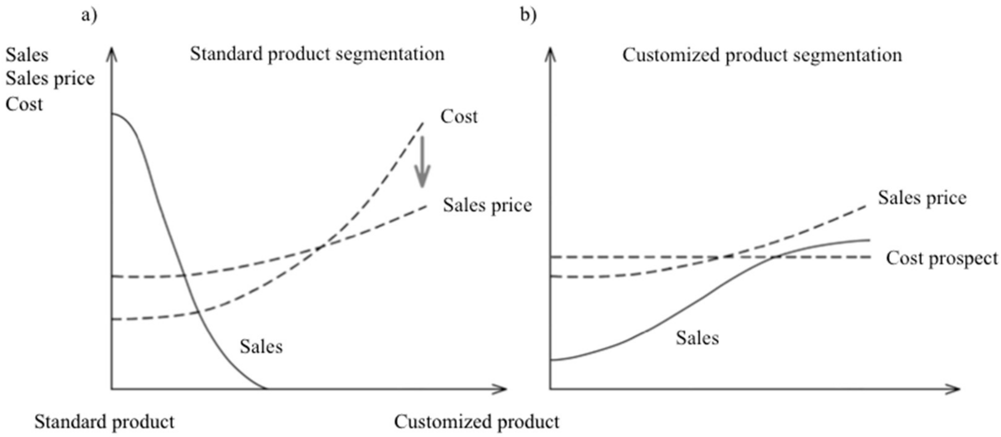


Fig. 2. (a) Illustrates how cost increase with the product's level of customization[12], assuming a product architecture suitable for standard products; (b) Illustrates a hypothesized cost prospect of implementing a flexible product architecture. It involves high fixed costs, however companies might save internal cost over time.

Followed by the assumption that a product becomes more complex as it is configured outside the design boundary of the present platform (see Fig. 1), the graph in Fig. 2a imply that the cost of a standard product is significantly lower than the cost of a customized product. When a company wants to modify their target market (see the adjusted curve of "Sales" in Fig. 2a, compared to Fig. 2b) to explore a new profitable though smaller market, it comes with a shift in platform definition and at a significant initial cost, although the cost of a customized product becomes significantly lower, as illustrated in Fig. 2b.

The goal of this study is to present alternative approaches on how to configure premium product variants with reduced internal cost, and to stress the distinction between strategies of limiting complexity and managing complexity in a short-term and long-term perspective.

### 2.3. Research Methodology

This paper is based on the theory of platform development and its correlation to configuring product variants. In order to substantiate theory concerning the automotive industry, ten interviews were conducted with senior-level engineers and managers working cross-functionally with configuration aspects of design. The interviews were transcribed and sent to the interviewees for verification. The results were hereafter analysed and categorized. Further, as a second phase of the study, the interviewees were invited to a workshop in order to discuss the results for internal consistency. This workshop was focused around the three different topics presented in section 4. Finally, a presentation of the conclusions was held at the case company to validate the results and suggestions for improvement, as well as conceivable future studies. Due to the verification and validation aspects, the internal and external acceptance of the findings indicates possible high impact of this study on the future of configuration principles.

## 3. Describing Alternative Approaches to Configuration

In the automotive industry, most companies adhere to similar product architectural approaches, namely by describing interactions between physical models and parts. The product architecture is in this context seldom contrasted from a structural point of view. Instead of rigid part structures, a more flexible approach may be built up by generic functional requirements (FR), which provides the opportunity to find several parallel conceptual design solutions (DS) to one FR, as in the design rationale (DR)[13].

### *3.1. Modular Approach*

The main objective of a Modular approach is to find maximum product offerings with minimal internal product variation. As expressed by Baldwin and Clark, it aims at ”*building a complex product or process from smaller subsystems that can be designed independently yet function together as a whole*”[14]. Ulrich and Eppinger further note that “*the most important characteristic of a product's architecture is its modularity*”[15]. In order to achieve the objectives of the Modular approach, standardized interfaces and surrounding environment constraints are essential. Thus, specifying coupled standards and rules[3]. However, to create a successful strategy of product modules, substantial changes in products and the development process must be considered[16].

### *3.2. Configurable Component Approach*

The objectives of a platform based on Configurable Components are to handle both complexity and variability. The approach therefore contains reusable platform elements modelled as autonomous, generic, configurable system families. The approach applies principles based on systems theory and design theory. A fully configurable platform element can be reused for 1) new development of platform systems aimed for original or new settings, 2) extension of original platform bandwidth in engineer-to-order settings, and 3) ordered configuration of quality assured variants within the platform bandwidth[9]. A system description composed of such models contains information about both the system solution itself, the means to compose system variants and also its underlying requirements and motivations, i.e. its design rationale.

## 4. Empirical Data and Analysis

The conducted interviews at the company have given insight into the current state of practice in the automotive business. The current paradigm is to reduce variability in order to reduce cost. Also, contradicting opinions concerning the company's focus of today, and future goals were found. These have been elaborated out of the following three themes.

- Why do we have so many “low-selling” variants?
  *More than 80% of the available variants are not sold in quantity. How do we sell our products today? How do we want to sell our products in the future?*

- What is it that the customer really wants?
  *Which features do we need to offer and which ones should be included? Is customer choice a competitive advantage? What is our market segmentation?*

- How can we solve the configuration difficulties?
  *Do we want to limit or manage complexity? How do we proceed?*

The company adheres to their existing architectural approach. Yet, they still want to manage complexity in a short-term perspective while developing benefits, such as economies of scale and increased commonality. If the company desires to facilitate benefits of economies of scale and commonality for customized products, the existing architectural approach is not viable. In this paradigm, the company makes debateable and short-term changes by optimizing configuration rules and reducing variants.

In this case, part-based structures, configuration rules and design solutions represent variants of a car. This approach is limited and does not serve customized product segmentation. A preferred approach of managing complexity for customized products would be the Modular one followed by a transition to the CC approach. The directed arrow illustrated in Fig.3 represents this path.

It is also noteworthy that the perceived cost of limiting complexity is typically low. However, when limiting complexity in a long-term perspective, the aggregate cost of all short-term changes in fact become very high. Likewise, the investment of a changed architectural approach may, in a given time frame, also be equal to the cost of limiting complexity in a long-term perspective. The main difference between these two, and the aggregate cost of their individual implementation, is a strategy of 1) limiting complexity of existing architecture, or 2) managing complexity of a changed architecture.

The analysed data from the interviews and the discussions from the workshop are summarized in Fig. 3.

| | Short-term | Long-term |
|---|---|---|
| **Manage product complexity** | **DESIRED SITUATION**<br>***Existing architectural approach***<br>*Offer customized products*<br>*Sell premium products*<br>*Economies of scale*<br>*Commonality*<br>*(no cost)* **NOT VIABLE** | **ALTERNATIVE SITUATION**<br>***Changed architectural approach***<br>*Offer customized products*<br>*Sell premium products*<br>*Economies of scale*<br>*Commonality*<br>**FEASIBLE** *(high perceived cost)* |
| **Limit product complexity** | *(low perceived cost)* **POSSIBLE**<br>***Existing architectural approach***<br>*Offer standard products*<br>*Aim for premium segment*<br>*Optimize configuration rules*<br>*Reduce variants*<br>**AS-IS** | **POSSIBLE** *(high hidden cost)*<br>***Existing architectural approach***<br>*Offer standard products*<br>*Risk of loosing premium segment*<br>*Optimize configuration rules*<br>*Reduce variants*<br>**UNDESIRABLE SITUATION** |

Fig. 3. Illustrates the paradigms of a contradicting “DESIRED SITUATION”, “AS-IS” and conceivable long-term “UNDESIRABLE SITUATION” as well as a feasible direction towards “ALTERNATIVE SITUATION”.

## 5. Discussion

The company has a desire to reduce complexity in a short-term perspective while using their existing architectural approach to develop and produce customized, low-cost, premium products. This indicates the lack of a clear strategy and that the company has to decide whether to focus on limit (standardize) or manage (enable variability) complexity. Thus, the company needs to decide weather to deliver a premium standard product or a premium customized product. The main difference between the two is related to either technical aspects, as in a changed product architecture, or marketing aspects, such as substantial branding. However, it seems that there is a more profitable, and unexplored, market in the customized premium segment rather than in the standard premium segment. Both are however viable. A step towards a strategy of highly customized products requires a change of the product architecture. An outlined proposition, discussing why, where and how to embark on this journey is given by the following.

### *5.1. Why to Consider Managing Complexity by Widening the Platform Boundary*

The company's planned approach is to optimize configuration rules, reduce variants or both. However, these approaches only consider emerging configuration issues and corresponding, very short-term, solutions to limit the complexity.

Essentially, the Modular approach is a long-term investment, whilst the CC approach is an even longer one. In these long-term perspectives, the cost of development and manufacturing of customized products is significantly reduced. In these settings the desire of economies of scale and commonality can be achieved. However, a flexible product architecture do not widen the platform boundary alone. Reconfigurable manufacturing systems, further discussed by Koren et al.[10] as well as Michaelis and Johannesson[11], can be applied with benefits of letting machinery being utilized for a significantly longer time compared with today. For example, it may allow an arbitrary car door to be configured into a front door, a back door, or even a trunk cover. In this sense, future platform preparation comes with lower risk, due to the wide platform boundary, and thus its flexibility. Besides, the architectural flexibility of the CC approach offers the ability to engineer-to-order.

### *5.2. Identification of Suitable Areas in Need of a Flexible Product Architecture*

When considering a possible implementation of a new architectural approach, one needs to be cautious in the sense of where to start since the transition involves significant changes. In some cases a Modular approach is suitable, while in other settings an even more flexible approach, as in CC, is feasible and necessary. Likewise, there is no need to force a parametric approach, as in CC, into a standardized component – a M10 screw for example. Instead it is wise to consider the CC approach in areas of the product's architecture where redesign is commonplace and persistent. Also, it is viable to implement the CC approach in local subsystems that recur in many global main systems, as in the example of the door explained above. Both the Modular approach and the CC approach are indeed two architectural approaches viable for managing product complexity. However, the implementation is critical and should be further studied in order to form a fully feasible, possibly hybrid, concept of the two.

### *5.3. Suggesting a Modular Approach Followed by a CC step-by-step Approach*

The platform-based configuration alternatives of a Modular approach and a CC approach are not as dissimilar, as it may seem. In order to implement one of the approaches in a broad sense, a large number of changes have to be taken into account, such as affecting people's attitudes, political resistance and the way to design and manufacture products. Thus, the approaches cannot be implemented short-term; they rather need to be adopted stepwise. A hierarchical well-defined product structure is a suitable base for a CC implementation, and this is offered by a modular product architecture. This means that a platform based on modules may be a viable first step, both to manage complexity and, in long-term as a baseline, to introduce CCs out of strictly limited modules. In this sense, it is wise to verify benefits on a small scale by introducing the CC approach in one module at a time. Then, if benefits can be proven, one may, gradually, transform additional modules into CCs, as continuous improvements. A CC platform based on a Modular approach might impose a very long platform life, for many generations of new cars. This can motivate the high initial cost of such an investment. In a business where changes constantly need to be incorporated, a CC platform may carry the flexibility needed to prepare for change and manage complexity over time.

## 6. Conclusions

This paper deals with the challenge of configuring premium cars to changing customer needs. Today, internal costs increase with increasing product complexity. We believe that the company studied can prepare to configure premium cars more flexibly and at lower cost. However, it depends on their choice of either limiting or managing complexity. If the company chooses to limit complexity we suggest optimizing configuration rules, reducing variants or both. On the contrary, if they choose to manage complexity we propose, and discuss, two different approaches: strictly restricted with well-defined interfaces, as in the Modular approach, or fully configurable, as in the CC approach. Both approaches come with a high initial cost. Although, the integral cost will eventually be reduced when a large number of variants are needed. A drawback of the CC approach is that it requires more flexibility in the manufacturing systems as well as the development processes, while the Modular approach might impose high restrictions on important customer needs, e.g., exterior styling.

We strongly recommend the company to manage complexity to prepare for change and reduce internal cost over time. However, this requires changes in the way the company designs and manufactures its products. The Modular approach is a low-cost approach that may have minor affects on how manufacturing systems are designed. In contrast, the CC approach is the solution that drives the establishment of a reconfigurable manufacturing plant that can produce customized premium cars in an engineer-to-order setting. Since the automotive passenger car industry is highly competitive, such new approaches on configuration might be necessary to be competitive in the future.

Due to the number of changes needed to manage complexity, a stepwise platform preparation approach for configuring products more cost efficiently is suggested. The Modular approach may be a well-suited step towards a CC approach applied on modules. Thus, a module can be managed flexibly, but as a part of a strictly hierarchical product structure, set by the modular system. However, this hypothesis needs to be further studied within the area of platform preparation and the concept of a flexible product architecture, aligned with reconfigurable manufacturing systems.

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