KEYWORDS
Product variants, variant management, modular design, product costs.

ABSTRACT
Product variety is necessary to satisfy the market. The change from a vendor market to a customer market has led to increased competition among manufacturers, benefiting the customer. Accordingly, less busy market niches are sought and more specific customer wishes are fulfilled. Rapid improvements or design of new products generate new incentives to buy. This market trend increases the variety of product variants while simultaneously leading to smaller number and lot size per variant. An increase in the number of variants and a decrease in the lot size tend to lead to longer throughput and delivery times and problems of quality assurance, and to higher direct and indirect costs per variant. The paper discusses this problem and provides a set of recommendations for controlling the multiplicity of variants within an enterprise.

INTRODUCTION
Over the past several years, a change from a vendor market to a customer market has led to increased competition among manufacturers, which has benefited the customer. Many manufacturers that did not adjust to this change were left in dire straits. Rapid improvements or design of new products generate new incentives to buy. This market trend increases the variety of product variants while simultaneously leading to smaller number and lot size per variant. An increase in the number of variants and a decrease in the lot size tend to lead to longer throughput and delivery times and problems of quality assurance and to higher direct and indirect costs (complexity costs) per variant. There are two ways to address the problem: reduce product variety, or, apply mass customization. The latter is finding increasing use, but is limited as to the types of products, in particular, to electronic systems and sheet metal parts [1], that are amenable to flexible manufacturing. For general mechanical products it has found limited use thus far; a start is being made in applying the method to mechatronic systems. Automobiles for example, where units rolling off the assembly line are customized to individual orders, can be regarded as a combination of the two. On one hand it is a matter of managing the variants, on the other looking at customer data to arrive at a proper price to cost ratio for the promising items. This paper addresses measures by which the multiplicity of variants within an enterprise is controlled. In this regard modular design and design in size ranges provide the necessary flexibility, at the same time possibilities for cost control.

In order to put variants in perspective, consider design phases and types of design. Not every project needs to be carried through all of the design phases: conceptual, embodiment and final design. The phase at which we begin depends on the type of design - the degree of originality involved. In this respect designs may be classified, as shown by Ehrlenpsiel [2], into (a) original, (b) adaptive or (c) variant designs. These are defined as follows:

Original designs: These involve developing new solutions. In such cases we begin with conceptual design. About 25% of all designs fall in this category.

Adaptive designs: In such designs a known solution is adapted to a new task. The general structure of the product is
better known in this case. Only new shapes, motions and perhaps materials need to be investigated.

**Variant designs**: In these designs sizes, materials, throughputs and arrangements in an existing solution are varied. Development of modular products falls in this category. In these cases only new detail designing is necessary. About 20% of all designs are variant designs. Instances of this type of design are the subject of this paper. Schubert, et al [3] cite the automotive supply industry, where products are designed by variant design. From these projects, it is known that the variant design process is based on use of existing variants. The designer selects the most familiar product variant; thus usually the most recent product is the common choice as initial point of design. As this design model is used repeatedly, the CAD models get more complex with every new variant. The features which became redundant during the design process often remain in the CAD model. These features continue in later product generations. Thus the manufacturing process becomes more expensive.

**VARIANT MANAGEMENT**

Variant management includes all measures by which the multiplicity of variants within an enterprise is deliberately influenced, Franke, et al [4]. This is valid, therefore, for products as well as for the affected processes. The aim is the reduction and control of complexity (i.e., minimum internal complexity and/or variant variety) while simultaneously offering sufficient number of variants to the outside (i.e., to the customer). Variant management should achieve the following aims: Servicing the market only with the necessary variants (variation needed in the market); recognition of and reducing the unnecessary variants, and decreasing the throughput times and, in particular, the direct and indirect costs, with the necessary variants. The variant variety can refer to: Product variants that become visible to the customer from the outside (e.g., in the variation of performance, size, equipment, materials, or the exterior design), and assembly and part variants which are internal, in different shapes or production and assembly methods. Next to the variants mentioned above on the product and part level, a large assortment of unrecognized variants often exists in the form of shapes, basic solutions for the same function, and of production processes.

Within a company, the causes of variant multiplicity can be classified as external and internal. The external causes result from factors such as market, competition, and technology upon which the company has little influence. Internal causes can be ascribed mainly to organizational and technical deficits that lead to an unnecessary number of variants at the product and part levels.

Increasing part complexity implies many variant-specific parts and fewer standardized parts. It is a result of the increased variant variety on product level, a low carryover of existing parts to newer products, and a high proportion of new designs instead of designs that only involve modifications (adaptive designs). A lack of transfer of existing parts results from not having an overview of the product range and the interfaces between the individual components. Possibilities for standardization are often not clear. The following can all lead to an increase in production complexity: A large number of self-designed parts and components; variants arising at an earlier step of adding value; and order- or customer-oriented individualization at an early stage of the production process. The results are small quantities per product as well as a large number and/or diversity of the parts used (part complexity). This results in an increasing number of tasks to be solved in production, smaller lot sizes, and a more frequent readjustment of production, which requires flexible machine concepts that increase process complexity and require greater coordination.

Alongside variant variety is the idea of complexity. Design and production are multi-layered procedures. Complexity costs are the costs resulting from these multiple layers. We distinguish between internal and external complexity (for example, complicated legal regulations). The causes and characteristics of internal complexity are the variant number and/or the extent of the overall program, the structure of the products (part and component number), and the chosen organization of production. To these, we add the customer structure and/or number of customers, the design and production strengths and weaknesses, the number of suppliers, and the number of employees and functions participating in order fulfilment.

An investigation of successful and less successful companies showed that increasing complexity becomes easier to control with the strategy of “simplicity and deciding on the focal points.” This affects the five “variety” problem areas, Rommel, et al [5] represented in Figure 1, i.e., the variety of parts, products, orders, suppliers and customers. Companies that enjoy long-term success are characterized in a statistically significant way by: Less product variety (concentration on strong products, elimination of products with low sales); less customer variety (concentration on high-value customers); fewer suppliers (integration into the company's design and
development, reliance for the long-term). Thus, reductions in capital flow, reduced part variety, and a less extensive inventory are also attained. Segmentation of production into product, which is made possible by a variation apparent from production and assembly islands (teamwork) with responsibility within the group, simplifies planning and logistics. Increase of outsourcing also reduces the number of variants to be planned within the company, since these are shifted to the suppliers.

Furthermore, individual departments in the company have different aims that may conflict with each other. Marketing requires more variants for market and customer-oriented strategic reasons, while production favours a higher degree of standardization and uniformity for efficient production. This complication in the goals requires expensive coordination. A lack of communication, coordination, and cooperation within and between the groups can lead to a dominance of the marketing group relative to design, development, and production. In its own interests, marketing frequently works against attempts at variant reduction. This comes about due to having a purely sales viewpoint, or ignorance of the cost consequences. The customer is promised fulfilment of all individual wishes and the result is an increased number of product variants. The same holds for the standards group. If they are not effective in checking company-internal standards, the standardization of components occurs too late. This department's potential does not end there, often because the standards department is organizationally in the wrong place, which makes it too weak. The deficiencies concerning information are closely associated with poor communication. Not having knowledge of the variant variety, inadequate description of product structure, unclear description of variants, and insufficient information flow regarding the recognition and description of the current variant variety all make it impossible to use the available information. Continuous improvement of future products thus becomes more difficult.

Markets are becoming increasingly complex, demanding special features, reducing needs for standard products. International pressure forces consumer products companies to a greater variety, while international competition presents greater variety to the market, forcing companies to develop new and unique products, different for various countries, as well as shorter development cycles. Technological progress favors the changing customer preferences but also the forces a continuous development of products. Internally, variants can grow from organizational shortcomings. These include impulsive actions by management regarding products, lack of coordination between divisions, communication failures, and lack of oversight on new parts development, standardization and dominance of marketing over development.

Variant variety provides advantages to the company, but also drawbacks. Variants satisfy needs of and provide benefits to different customers. With many customers, there is an aversion to a uniform response to their needs. Next to the use-benefit, there is also a value-benefit to be satisfied by the product, which is made possible by a variation apparent from the outside. Through appropriate product differentiation, it is possible to offer products in several price ranges and thus address different groups with differing purchasing power. On the other hand, variant variety increases the manufacturing costs, as well as the overhead costs in the areas of design and development, marketing, quality assurance, logistics (including materials management), and computation. That is where the activities that used to be necessary only once for a large number of the same products (parts) now arise repeatedly for almost every product sold. Since rising product and part counts are also tied to a corresponding increase in the variety of customers, suppliers, and orders, the degree of complexity climbs in all groups and departments, which means an increase in the organizational expense.

Variant management involves trade-offs: A sufficiently large number of variants are needed to do justice to the different customer wishes. At the same time, the cost increase due to the increasing number of variants (for example, in design and development, part management, etc.) should not be so high that prices become unattractive to the customer.

In establishing the correct number of variants, the market requirements and the product range offered must be examined. Most important is an analysis of the product and part variety. This includes an analysis of the variant variety in the product program and an analysis of variant variety for specific types of products. For the product program we need to look at sales, profit and number of products sold to specific customers. A Pareto analysis shows ranking of sales and profitability of different products. An interdisciplinary team will find which variants are profitable, which components can be reused, production processes which are optimal, and possibilities for creating part families. Such analysis will help deciding on the future product range. For specific product type a similar study will show the extent of part types, part quantities, and their modifications over the last several years (time history of the growth of item numbers. This can be the motivation to reduce the part count, using integral design or other concepts. Furthermore, the degree of standardization of a current product should be examined and compared with earlier or similar products. By that we understand, broadly speaking, the scale of the product standard. That is, to what extent the product program is standardized regarding types of performance and configurations, or to what extent are, for example, part families, size range of products, and modular design put to use. The aim is, in decreasing order of desirability, the use of standard parts, repeat parts, new parts similar to other parts, and finally, totally new parts. These are elaborated upon below.

Variants should be so designed that they are realized as late in the production process as possible, called postponement, Davis and Sasser [6], near the end of the final assembly. The variant tree gives direct insight into the number of possible and requested variants for a type of product. Rosenberg [7], Figure 2. The figure is self-explanatory; it uses the simple example of an automobile instrument panel. It shows which variants are in high demand and which should be dropped, unless the costs can be recouped. In other cases, the add-on parts are arranged according to their assembly sequence and the pertinent variant
variety is presented for every assembly procedure. A basis or carrier component starts this sequence. The add-on parts are mounted on the basis component, and thereby product variants arise. For comparison, it is advisable to set up a variant tree of a competing product.

### FEATURES

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**FIGURE 2 - Variant tree for an automobile instrument panel**

### DECREASING THE PRODUCT AND PART VARIETY

A decrease in the product variety is a strategic procedure of management in cooperation with marketing, sales, design and development, and production; it can be carried out after the analysis of the product program. In contrast to that, the decrease in the part variety is handled later. This involves a decrease of the part count per product and the number of the different parts. The most economical way is to avoid the origin of unnecessary variants right at the beginning of the design. We can divide the measures for decreasing the part variety into the following, which partly overlap:

**Increase the degree of part standardization; use same parts and repeat parts**

Cost savings are achieved by the use of standard and purchase parts and through the standardization of products. Advantages are their reliability and interchangeability, as they are readily available. On the other hand, what is needed is not always available on the open market, in a global market regional and national standards complicate the picture; standards change over time.

Standardization is also possible through, or in cooperation with suppliers of purchase parts, e.g., the increasing online access that includes its direct incorporation into CAD. Purchase parts are parts, assemblies, or products that are bought from suppliers. They may be standardized by the supplier for the open market, or for a customer according to latter’s specification, making them optimal for the application. Advantages of using standard and purchase parts include:

- Standard elements are tried and tested, the interchangeability within the respective standard is assured.
- They correspond (as far as current) to the state of the art and are usually economical and available from stock at short notice.

Tools for use with standardized parts are also partly standardized and need not be expensive to produce (e.g., wrench).

To be sure there are disadvantages to using standard parts, e.g.,

- The number of the standardized design entities, parts, assemblies, or machines becomes hard to manage. For many companies, this leads to their own choice of a subset of the standard parts.

- In the course of globalization, the manufacturers are confronted with additional regional and national standards.

- Standards change, and so lead to the necessity for change in broad areas.

Standards can hinder technical progress, since known solutions are resorted to repeatedly and a systematic solution search seldom occurs.

On an individual basis, standard parts are often technically suboptimal.

With a revision or a new design, it is advised to hold the number of customer-specific new parts as low as possible and to use, as far as possible, the same parts in the company or obtained from outside. Thus the overhead costs as well as the direct costs are kept small.

**FIGURE 3 - Part categories of a complex product**

Figure 3 shows the classification of the parts of a product [2]:

- A **new part** is a part newly designed for the given product (internal or external design; "totally new, or similar to...").
- A **repeat part** is a part that was already used in other products (the same or different product type). Modular design parts are essentially repeat parts, insofar as they are not purchase or standardized parts. Repeat parts are defined by part families, products in size ranges or modular designs.
- A **same part** is a part that occurs repeatedly in a product. Examples are same housing covers or identical levers or bearings.

This enables the determination of the degree of standardization of a product. Besides purchased and standard parts, they are either new or repeat parts. New parts may be...
either totally new or similar to existing parts. This allows an estimation of the extra cost of a new product.

A new part, even if it has lower production cost, has initial costs associated with it, and thus a minimum number must be produced before a break-even point is reached, Figure 4.

![FIGURE 4 - Break-even point for a new part](image)

**Create design part families**

Design part families are defined as those in which the parts fulfil essentially the same function. Parts from a design part family are searched for with a catalog or search system. The search is aimed at existing but not standardized parts, to use these “as-is” (formation of repeat parts), similar parts, to be altered, standardized parts (locating drawings according to types and/or features), and partially standardized parts (templates and/or macros for entering parameters as needed for each order). The following example shows the saving potential for in-house standardization and part family creation. In Figure 5, the variant variety of the output coupling flange of a truck transmission was reduced to only two sizes, from hundreds before the rationalization [2]. Before the investigation, there were six main design sizes with 416 dimensions. After the investigation, there were only seven left, when only two sizes of the length proved to be necessary. All other sizes arose due to uncoordinated dimensioning by different designers.

**Favour integral design**

Integral design means the combination of several parts into one part, usually made of the same material; differential design is the opposite. Part count decrease becomes possible mostly by a change in the production process, typically to molding, sintering, sheet metal forming, forging, deep drawing and erosive, electrolytic removal. In differential design two or more sub-parts are assembled to form the part. In general, integral design is preferable for small to medium size parts and for large quantities. This is because the per-part tool, model, and setup costs (all introductory or one-time costs) are less important. The reduction in the processing, joining, and assembly costs is greater. Also, if there are no joints, these parts (faces) do not need to be machined or joined. In general, assembly becomes easier, in part because of the falling logistics costs. Differential design can, on the other hand, lead to lower costs in single-unit and limited-lot production for large parts.

**FIGURE 5 - A design-part family**

**FIGURE 6 - Integral or differential design of a pinion shaft**

Rules of thumb are: Integral design is more economical for small quantities and processing from the whole, particularly for small and medium-size parts. Differential design is more economical for large parts or with expensive material in single-unit production and for small quantities. Figure 6, Ehrlenspiel
and Fischer [8], shows a pinion shaft in differential and integral design. A small shaft is shown above (Ø 66 mm, 1.6 kg). Compared to the materials costs, the setup costs are dominant in case of single-unit production. Thus, it is not profitable to make the pinion shaft from two parts just to save on the material being removed. The low-cost alternative is the integral design in which the pinion shaft is machined out of one piece.

Organizational measures
Lack of communication between designers of similar products and with production, cost accounting and materials management plays a key role in the proliferation of variants. Process cost accounting for the evaluation of the introduction and change costs can show the true costs of new variants. It is realistic to put a cost handicap on a new variant, which must be matched by cost reduction elsewhere.

Design of products in size ranges
Product made in series of sizes, e.g., motors and compressors are the most effective means to standardize a product over a specific size range and thereby to strictly limit the part variety. Products in size ranges are usually combined with modular design. An example from experience: automobile manufacturers cover a certain size range with the different models; also, upon request, different engines and interior furnishings are installed from a modular system. Such products have identical function (qualitative), design features, and most possibly, materials and production. They might differ in performance data (function, quantitative) and measurements, and quantities dependent on those (weight, costs etc.) The purpose is to cover a wide field of application of a product category with minimally different product models in order to achieve cost reduction, delivery time contraction and an increase in quality and reliability.

Modular designs
Modular designs are developed for limiting the multiplicity of special designs and the associated variant variety that come about in ordinary practice, without going deeper into the methodology. Modular design refers to a combination system of building blocks (elements) of different or same function and shape. By using elements with different functions, we get an overall system of different overall function (example: a handyman's multi-purpose tool set). By using elements with the same function, we get a size change, but with same overall function (example: factory halls, bridges). Figure 7 shows the cost reduction achieved in the case of an industrial crane made as a modular design. The most important elements are produced in larger quantities. Thus the one-time processing costs per piece are reduced in production, storage, purchasing, customer service, and in all overhead cost departments (e.g., design, sales).

Use of platforms
If the same parts are planned and standardized for several products, we can speak of platforms. Platforms are used, e.g., by car manufacturers; a notable example in the US was by Chrysler in the K-car series. Unlike the usual modular designs where the elements are defined once and then used unchanged, with platforms it is necessary and possible to adapt to the different modifications. Platforms minimize the costs of development, licensing, tooling, etc. that are often high. With platforms we can define particular parts such as specific sensors for a whole engine family; complex assemblies such as the basic assembly of the automobile body; or complex subsystems such as the automobile seat. Corresponding examples are found in many fields where products are made in series. What is important is that the platform should not be visible to the customer; otherwise, the individuality of the products would be lost. In the Volkswagen Company there is a so-called “hat” that is put on top of a platform. It refers to the outer skin of the respective vehicle, e.g., VW Golf, Skoda, Audi, Seat. The hat is visible to the customer and is put on the platform, Kruschewitz [9]. This means that millions in development and production costs were saved. Products such as refrigerators, stoves, etc., are frequently produced under different brand names and with different designs from one manufacturer, with a very high proportion of similar parts.

Advantages of using platforms are: The production quantities increase through standardization, which can lead to considerable cost reductions; development times decrease since the platform solutions can be applied in several products simultaneously; innovations are thus transferred at an accelerated rate, and the logistic processes in the company are unburdened by the reduction of materials flow. Parts and assemblies of all of a car manufacturer’s models, for example, are supplied from the same sites. There are the following disadvantages: The standard platform can become a brake on
innovation, since at times the importance of a larger product family must be considered, and inept advertising or publication of information that describes the platform design of different products can give rise to a cannibalization of the different products among each other.

**MASS CUSTOMIZATION**

Mass-produced goods become commodities that can be easily produced by competitors and supplied at lower cost. As customers become better informed, they become more discriminating and demand individualized products. There is a continuous spectrum from mass production (products made in quantities and marketed to promote consumer demand) through mass personalization (customer is involved at the final stages, selecting options from a standard base product; examples are automobiles and PC’s) to mass customization. Mass customization aims to create variety in products that are specially designed to be produced by flexible, quickly changeable manufacturing processes. Mass production achieves lower costs by economies of scale and production experience. These are combined with customization to satisfy customer demands. A few pertinent examples are the following:

Graessler [10] shows the application of modular structures in developing mechatronic systems for automobiles, customized for individual needs. A balance is aimed for in the external demand for and internal costs of product variety. Mechatronic systems comprise of mechanical, electrical and analog and digital electronic components. Flexibility is achieved by focusing the changeable portion of the system in the programmable digital subsystem. The overall product is of modular design. A predefined range of customized products foresees a range of commonalities in requirements, design concepts, through production and operation. All these products have a common architecture. Erens and Verhulst [11] analyze the role of architectures in the development of product families, in order to resolve the conflicting requirements of modularity and integration.

Walla, et al [12] emphasize the importance of collaboration between design and production groups for an efficient product realization process. They look at the influences of a standardized and modularized production on the product design and present the requirements and restrictions which have to be taken into account in an early phase of the development process. This enables flexible production processes which are easily adapted to changing product designs.

Customization applied to electric motor production is described by Brown [13]. A manufacturer of fractional and low horse power motors is able to deliver motors in lot sizes from one to 100 or more. They achieved this by redesigning both the products and the production lines. The basic concept of using same and similar parts such as end plates and winding details was applied.

**CONCLUSIONS**

Market studies made for estimating customer demand are of varying accuracy. Ranging from a “captive customer” where an order is being fulfilled, to a new product for the general market, there is a spectrum of scenarios.

In order to deal with the conflicting requirements from customers and conflicts within the company, there is a range of possibilities for limiting the variant variety to product and part level and to process level. To satisfy the virtually infinite number of customer wishes with the smallest possible number of variants, it is necessary to attempt a variety of measures. Whereas external causes of variant growth are generally beyond direct control, the company should pay attention to the internal factors mentioned earlier.

Due to flawed communication and standardization in the machine industry (even without influence from the market or marketing), new, unnecessary variants are always coming out. Ironically, as far as the orders are concerned, with almost similar products many parts could be identical. This is because designers (let us say A, B and C) who work on almost the same orders do not know much about each other's job, and each lays out details of the design differently. The same thing occurs during work schedule preparation. In addition, the search for same or similar parts that are already available, is often very laborious. From the internal causes of the growth of variants, it can also be assumed that the different departments of a company have different requirements and tasks regarding variant management.

Figure 8 shows effect of variant control. The left part of the figure shows how, without variant management, the individual customer preferences are realized by 100% individual modules (assemblies, parts, etc.), in addition to the usual standard parts. The right side of the figure shows how the number of customer choices can be kept within limits by using different standardization approaches.

Below are two very different examples, from automobile manufacturing and from plant engineering:

A **racing car** contains some standard and purchase parts, but will be predominantly made of individually designed and produced parts. For such a product the demand for optimal performance is foremost, despite other demands and possible
cost savings from the use of standard parts. On the other hand, for a high-volume automobile many customer wishes have to be satisfied with low costs if possible. Therefore, such a car is largely produced from especially developed parts that are, for all practical purposes, standard parts because of the large quantities made. Special wishes that were not pre-planned are either not filled, or filled only at high costs.

In the storage and handling field (moving, storage, and handling of materials), special solutions are developed for each customer. For example, in parts assembly, clothes manufacture, warehousing, etc., every plant design must be adapted to the customer-specific products, the throughput quantities, the space limitations, etc. Such plants can have from 500 to one million parts. The number of different parts can range from 100 to 1000. To cope with these quantities and the variety of parts, modular designs are applied constructively and organizationally, within a given time, while continually being aware of costs, modular designs are applied in many different forms.

Recommendations

In the preceding discussion a range of possibilities were shown for limiting the variant variety to product and part level and to process level. The discussion shows, in part, different perspectives and focal points. The proven results are summarised in the following recommendations:

Marketing department is intended to understand customer wishes. Marketing people must consider the costs, not just the market size, thus reduce the large number of different requirements to a reasonable size.

Design and development play an essential role in the variant situation in a company. Appropriate arrangement of the technical interfaces affects the flexibility of a product. By using the same components in different products, the number of individual adaptive designs can be restricted. Variants should arise as late as possible in the product realization sequence, which calls for an appropriate product concept. Appropriate help should be available to support design and development by supplying the department with information during design and development, or to simplify the design process itself. In working with variants, the type of design of the products being considered plays an important role in this respect. This is because the measures and approaches for avoiding or controlling the variants are dependent on the processing strength and weakness of the products.

Production should entail the least expenditure. A decrease in mounting and setup times is possible with suitable design of the parts being produced. In a manufacturing company, variant management without collaboration of the production personnel is inconceivable. This department can supply decisive input to design in developing production-oriented part families, for example.

Similar statements are valid for assembly. Timely attention to information on assembly techniques leads to assembly-oriented part families.

The customer service department needs an overview of the variants produced and possible distinct service guidelines for the individual variants.

REFERENCES