Contribution to an automotive variant-driven product variety framework: influencing factors and impacts

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Abstract
This paper focuses on influencing factors and respective impacts of proliferation of product variety in automotive supply chains. A systematic framework for evaluation and management of variant-driven product variety has been developed. Influencing factors and impacts have been organized each by three dimensions. A matrix of variety factors and impacts has been achieved respectively.

Keywords: Product variety, Automotive industry, Influencing factors

Introduction
The automotive industry has to balance difficulties and benefits of high product variety. On the negative side there are increased overhead costs, challenging coordination and often poor logistics performance; on the positive side high margins from special selectable features raise the overall profit. In fact, mostly it is problematic to allocate costs of additional variants to the profits of expected additional sales. One reason is the wide and differing origins of product variety: platform, models, variants and dealer-fitted options (Scavarda et al. 2009). It is vital to identify the driving factors and impacts of product variety before managing it with regard to the respective cause. Despite being aware that the diversity of variants is one of the main causes for variety, there is still a void of systematic analysis of factors and impacts. Some of them, such as more energy consumption and emission, are seen critical in public and press, but have not been analyzed before the background of variety. This paper focuses on influencing factors and respective impacts of proliferation of variant-driven product variety in automotive supply chains.

The following discussion is structured into four sections. The next section two reviews and summarizes the related literature. In section three and four factors and impacts of product variety in the automotive industry are analyzed and classified respectively. The last section concludes and discusses forthcoming studies.

Literature review
Many researchers have already dedicated to the study of product variety and corresponding complexity in the automotive industry. Also many other industries have been analyzed. The most

relevant references for this project are summarized after introduction of relevant terms.

Definitions of relevant terms

It is necessary to give the definitions of relevant terms in variant-driven variety management to define the range and emphasis of this paper.

A **product variant** refers to the discrete product that will be offered to the customers. Product variants are a series of finished products, which are part of a variant family and differ by at least one characteristic value (Lechner 2011, Roy et al. 2011).

A **part variant** is defined as a part or subassembly that comprises the parent structure of the product variants. Part variants refer to the similar variants which differ by at least one characteristic value in a part type, e.g. aluminum cast wheel and steel wheel are two part variants of the part type wheel (Lechner 2011, Roy et al. 2011).

Variant-driven complexity refers to the complexity arising from variety caused by diversity of part variants (Kersten et al. 2006, Lechner 2011).

Factors of product variety in the automotive industry

Product variety is an effective strategy to increase market share (Scavarda et al. 2009) and attract customers (Pil and Holweg 2004). There are many causes which induce companies to expand the product variety. Table 1 summarizes the results from the respective literature research. It can be found that less attention is given to product and supply chain factors than to market ones.

Table 1 - Factors of product variety and corresponding researchers

Factors	Researchers
Scope of Marketplace	Berry and Cooper 1999, Fujimoto et al. 2003, Martin and Ishii 1997, Pine and Davis 1993, Scavarda et al. 2009, Schleich et al. 2005, Silveira 1998, Swaminathan and Nitsch 2007
Demand Fluctuation	Chakravarty and Balakrishnan 2001, Kaluza et al. 2006, Pil and Holweg 2004, Ramdas 2003, Scavarda et al. 2009, Schleich et al. 2005
Product Customization	Martin and Ishii 1997
Maturity of Marketplace	Pine and Davis 1993, Scavarda et al. 2009
Laws and Rules	Fujimoto et al. 2003, Schleich et al. 2005
Product Life Cycle	Chakravarty and Balakrishnan 2001, Pil and Holweg 2004, Ramdas 2003
Product Development Process	Schleich et al. 2005
Frequency of Production Planning	Chakravarty and Balakrishnan 2001, Ramdas 2003
Positioning of the OPP	Kaluza et al. 2006
Order Allocation	Berry and Cooper 1999, Schleich et al. 2005, Silveira 1998
Sequencing	Kaluza et al. 2006
Transportation Mode to the OEM	Kaluza et al. 2006
Delivery Mode	Kaluza et al. 2006

Impacts of product variety in the automotive industry

Variant proliferation causes distortions that are often not immediately obvious (Schleich et al. 2005). Simply increasing variety may not guarantee the growth in long term profits, but may even worsen a firm's competitiveness (Ramdas 2003). Greater product variety may raise overhead costs, manufacturing replenishment times, retailers' costs, inventories and more. Table 2 summarizes the results of our literature research on product variety impacts. Surprisingly, some

impacts such as increased energy consumption and the need for additional working stations and thus corresponding plant spaces have been neglected in academic literature widely.

Table 2 - Impacts of product variety and researchers

Impacts	Researchers
Changes in structures of product, engineering and SC	Fisher et al. 1995, Fujimoto et al. 2003, Hu et al. 2008
More transaction, coordination effort and supervisory demands	Fisher et al. 1995, Fujimoto et al. 2003, Hu et al. 2008, MacDuffie et al. 1996, Ramdas 2003, Schleich et al. 2005
Longer flow times, setup times and lead time	Er and MacCarthy 2006, Fisher and Ittner 1996, Fisher and Ittner 1999, Fujimoto et al. 2003, Ittner and MacDuffie 1995, MacDuffie et al. 1996, Ramdas 2003, Schleich et al. 2005, Thonemann and Bradley 2002
Additional labor and training workers	Fisher and Ittner 1996, Fisher and Ittner 1999, Fisher et al. 1995, Ittner and MacDuffie 1995, Lechner et al. 2011, Schleich et al. 2005
More variants and suppliers	Benjaafar et al. 2004, Fujimoto et al. 2003
More inventory, safety stocks, plant and warehouse space, change in inventory policy	Benjaafar et al. 2004, Berry and Cooper 1999, Kersten et al. 2006, Er and MacCarthy 2006, Fisher and Ittner 1996, Fisher and Ittner 1999, Fujimoto et al. 2003, Hu et al. 2008, Ittner and MacDuffie 1995, Lechner et al. 2011
Fixed and semi-fixed investments of variety handling systems, more overhead costs	Berry and Cooper 1999, Kersten et al. 2006, Fisher and Ittner 1996, Fisher and Ittner 1999, Fisher et al. 1995, Ittner and MacDuffie 1995, Fujimoto et al. 2003, Pil and Holweg 2004, Roy et al. 2011, Scavarda et al 2010, Schleich et al. 2005
More retailers' costs	Thonemann and Bradley 2002
Difficult in line setting, feeding balancing and position of OPP	Fujimoto et al. 2003, Hu et al. 2008, MacDuffie et al. 1996
Lower utilization of facilities	Fujimoto et al. 2003
Risks of stockout and loss of major sales, reduction of profit	Berry and Cooper 1999, Kersten et al. 2006, Fisher et al. 1995, Ramdas 2003, Roy et al. 2011, Schleich et al. 2005
More contingency, quality defects, repairs and rework, productivity decline	Kersten et al. 2006, Fisher and Ittner 1996, Fisher and Ittner 1999, Fisher et al. 1995, Hu et al. 2008, Ittner and MacDuffie 1995, MacDuffie et al. 1996, Ramdas 2003, Schleich et al. 2005, Zhu et al. 2008

Variety problems in other industries

Table 3 - Literature on product variety in other industries

Industries	Factors and Impacts	Authors
Ready-to-eat product	Impacts: welfare economics	Scherer 1979
Retail trade	Factors: satisfying customers' needs over time and keeping their loyalty; Impacts: customers are confused with the wide assortment of options.	Huffman and Kahn 1998
Bicycle industry	Impacts: high investment costs and high logistic costs	Randall and Ulrich 2001
Intermediate goods	Impacts: change people's spending shares	Bils and Klenow 2001
Software industry	Impacts: hinder the performance of firm and product	Cottrell and Nault 2006
Fast moving consumer goods	Impacts: extend product line	Quelch and Kenny 1994

Many researchers have involved in product variety studies in other industries. This includes computer, general manufacturing, bicycle, luxury fashion, fast moving consumer goods, textile industries and more. The identified factors and impacts in these industries cannot be neglected as similarities to the automotive industry. The results are summarized in Table 3.

Significance of research trends in variety management

Many authors state that the actual variety provided by an uncontrolled market will not coincide with the socially optimal degree of variety (Scavarda et al. 2009, Schleich et al. 2005, Stäblein et al. 2011). Researchers who studied variety and corresponding complexity confirm without exceptions the significance of a suitable assessment and planning of variety (Benjaafar et al. 2004, Scavarda et al. 2009, Schleich et al. 2005, Thonemann and Bradley 2002). The object of variety management is to define and manage what constitutes product variety and variety costs. Non-surprisingly, variety management has emerged as a crucial dimension of successful business practice (Ramdas 2003). And complexity management arising from high levels of product variety is identified as crucial for automotive and other complex industries (Er and MacCarthy 2006, Roy et al. 2011). Thus, variety and complexity management should be launched even before start of production (Schleich et al. 2005).

Nevertheless, there is still a lack of understanding in the mechanisms and impacts of variety on manufacturing processes (Er and MacCarthy 2006). In fact, it is increasingly difficult to apprehend where and how variety is accommodated (Swaminathan and Nitsch 2007). Characteristics of the assembly system, such as its system configuration, its task to station assignment and the assembly sequences need to be taken into consideration (Zhu et al., 2008).

In automotive management it is necessary to specify the optimal number of variants (Martin and Ishii 1997, Stäblein et al. 2011) to achieve the goals of costs saving, high performance and even environmental protection. In order to answer such a question, a systematic evaluation of impacts of variant-driven product variety is essential. Nevertheless, any effect presupposes a cause. Only by identifying influencing factors of variety proliferation, the number of variant and the resulting variety can be evaluated and planned successfully. It is obvious that a summary and analysis of factors and impacts is necessary as a prerequisite and foundation of evaluation and management of variant-driven variety.

Influencing factors

Derived from Table 1, the influencing factors driving the expansion of variety shall be separated into three categories: market, product and supply chain (Klingebiel 2008). In the following these categories shall be analyzed and deduced scientifically.

Market

Developments of markets influence significantly the manufacturing processes as matching market demand is a basic requirement for a product to be accepted by customers. According to Table 1, five categories of market factors which influence product variety can be identified: demand fluctuation, product customization, scope of marketplace, maturity of market place, laws and rules.

Demand fluctuations: Many demand fluctuations are caused by characteristics of the product itself, (e.g. seasonal demand of products like Easter eggs). In the automotive industry, on the contrary, several external elements may increase demand fluctuations significantly. Weather, economic growth rate, salary growth of employees, even some special emergency may lead to

fluctuations, i.e. the rise or decline of consumers' purchases of a certain product. Of course, a company with fluctuating product demand will introduce diversification strategies, e.g. by enlarging the range or variety of specific products to attract customers in low seasons.

Product customization: Some companies try to provide as many choices as possible to customers by offering a wide choice of customization. The number of variants is of course positive correlated with the rate of the products which are customized. Usually, the automotive variants in developed countries are much more than those in emerging ones (Scavarda et al. 2010) because more people in developed countries prefer to customize a vehicle.

Scope of marketplace: Just like people's preferences for different product characteristics, different marketplaces have different demands for vehicles because of local culture, economical aspects, legal requirements or infrastructural prerequisites. For example, the antilock braking system (ABS) is offered as a standard feature for the Ford Fiesta hatchback in UK, whereas it is an optional feature in Brazil and Argentina, and even not available at all in Mexico and Chile (Scavarda et al. 2010).

Maturity of marketplace: A company has different objectives and innovation strategies in each stage of market maturity, which leads to distinctly offered product variety. In a low maturity stage, a company issues innovative products to a new market in order to conquer and expand the marketplace. The offered product variety is often low at that time. With the development of the market, more and more competitors launch substitutes and the automotive company issues more variants to consolidate its' market share and attract more customers. In a high maturity stage, it is necessary to only retain or even decrease the variants to get ready to switch to a new product.

Laws and rules: Every country/ region has its special laws and rules on technology, environmental protection, politics, traffic and more. Also, some advanced automobiles can't be offered in emerging market because of the lack of premium grade gasoline. Some countries restrict or prohibit automobiles beyond certain size or discharge volume in view of environment and economy. Those special laws and rules result in a quite dissimilar number of variants.

Product

It is no doubt that some characteristics of product itself influence the number of variety. The three characteristics product life cycles (PLC), product development processes, and the frequency of production planning may be identified as influencing factors in Table 1 which are resulted from product characteristics.

Product life cycles: PLC (Kerin et al. 2003) can be interpreted from two perspectives. From market perspective, product sales pass through four stages from introduction, growth, maturity to decline. This implies different sales revenues / profits and so distinct marketing, financing, manufacturing and human resource strategies in each stage. The requirement for product variety in each stage is few, more versions, full product line, and best sellers separately (Kerin et al. 2003). From engineering perspective, the PLC is interpreted as the development process of a product from conception, design and manufacture to service and disposal (Kerin et al. 2003), i.e. the product development process, which is discussed in the following.

Product development process: The product development process includes six circulatory phases from the idea generation, concept development, business opportunity assessment, market testing, and market validation to product launch (Adler et al. 1996). Issues and adaptations, working out of product details, materials, costs, possible failures and required regulations should be considered during the process. Any of them impose impacts on variety, e.g. the manufacturing

technology and company's financial situation limit the number of variants can be produced.

Frequency of production planning: Production planning determines the plan of every workshop, section, place and worker in a month, a week, a shift even an hour. The frequency of production planning is related to the production modes of manufacturing, which are, engineer to order (ETO), assembly to order (ATO), make to order (MTO) or make to stock (MTS) and positioning of the order penetration point (OPP) (Olhager 2003). The more frequent the production planning is executed, the shorter is its cycle time. So the planning may reflect the market demands more flexibly and quicker but optimization by batch production is more difficult. To supply great variety under a high frequency of production planning is a huge challenge for automotive manufacturing.

Supply chain

All nodes and paths in a supply chain are interrelated and interact on each other. It is natural that there are many factors of product variety in supply chains. According to Table 1, these factors are positioning of the OPP, order allocation, sequencing, transportation and delivery modes.

Positioning of the OPP: OPP affects the delivery strategy and the pull or push strategy of supply chain directly. These influences need to be discussed in terms of the whole supply chain. It is advantageous for agile manufacturing to expand the product variety according to the customers' wishes, but to shift the OPP downwards the supply chain. To other types of manufacturing companies, the same strategy may accelerate their failures (Olhager 2003).

Order allocation: Dealers and end consumers are two kinds of customers of an automotive original equipment manufacturer (OEM). Most cars are sold by dealers, who exhibit and sell some standard and high performance cars. In many countries, dealers order cars in large batches from the OEM in typical configurations, which is favorable to enhance productivity and optimize costs. Moreover, there is a growing tendency to delay configurations to the dealer lot as this late configuration decreases the variety in the OEM plant directly while fulfilling the requirements of customers with low costs at the same time (Scavarda et al. 2009). Nevertheless, customers with special demands can configure their cars as direct order at the cost of a higher price and longer lead time. These direct orders may be identified as the main source of the variant-driven complexity in the automotive industry.

Sequencing: Almost all the automotive manufacturers apply a mixed-model assembly system to control costs on the premise of an increasing variety and range of offered products, which necessarily causes a complex supply chain (Hu et al. 2008). Successful mixed-model assembly systems need effective car sequencing. Just in sequence (JIS) is an inventory and line-feeding strategy which has the advantageous of both just in time (JIT) and supply in sequence to satisfy the demands for line-feeding of huge variants in assembly line. An OEM can deal with huge variants successfully if there is enough sequencing capability to assembly line.

Transportation mode: It not directly obvious that the transportation mode of parts shall influence the product variety, but the logistics requirement in context of high product variety depends to great extent on a suitable transportation mode in parts supply. The different transportation modes, such as break bulk shipping, milk run or direct transports, have their individual characteristics and applicability in dealing effectively with the transports of part variants and vice versa.

Delivery mode: Similarly to the transportation mode, suitable delivery modes are needed to deliver the right automobiles to right customers at right time. The delivery mode should be matched with the supply chain mode and product development process. Self-run delivery can

guarantee the delivery efficiency but at high cost. Most automotive OEMs choose the third-party logistics (TPL) to delivery their products because of the high efficiency and low costs.

Summary of influencing factors

All discussed influencing factors on product variety and their characteristics are summarized in the presented categorization in Figure 1. Each factor influences differently depending on its value, e.g. it is obvious that a low demand fluctuation will contribute differently to the product variety from a seasonal demand fluctuation.

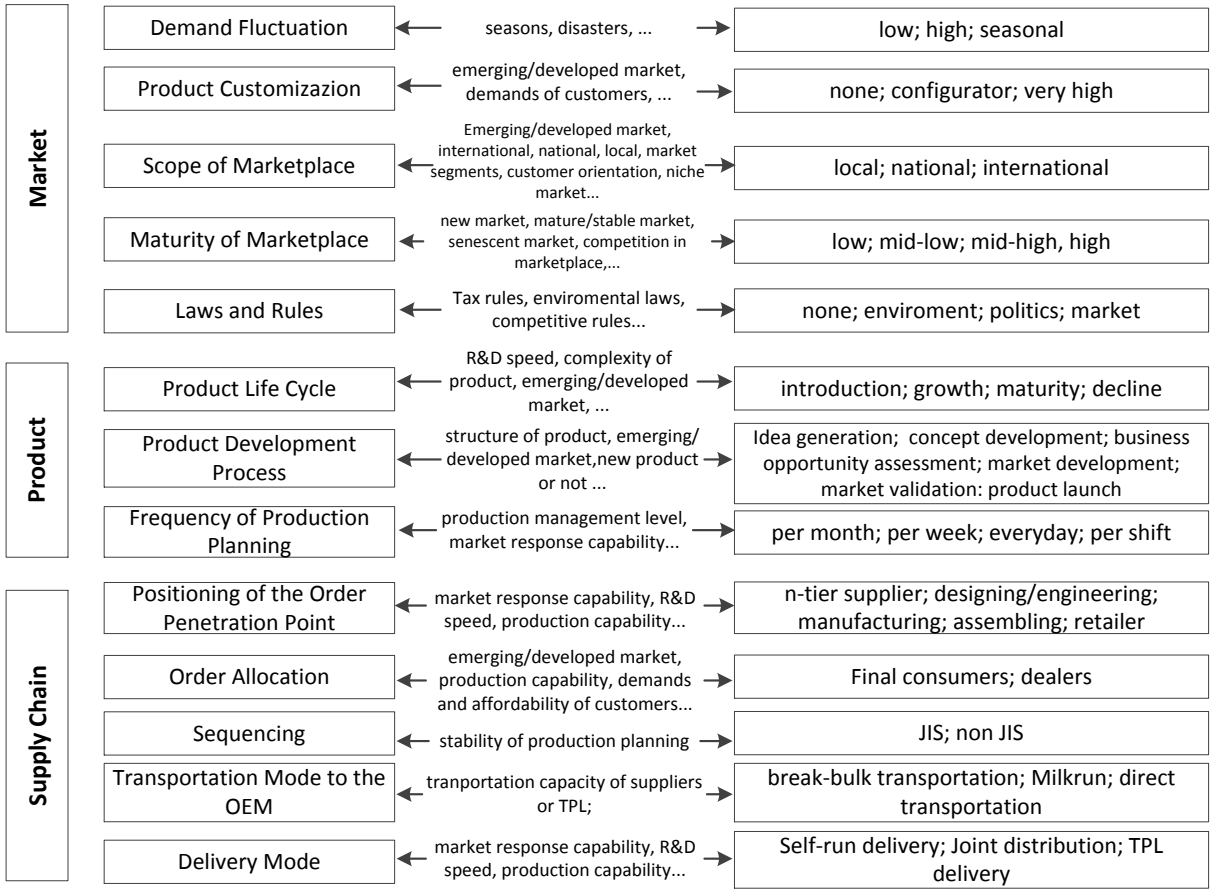

Figure 1 - Structure of influencing factors of variant-driven product variety

Impacts

A supply chain is characterized by its three aspects: processes, structures, resources (Kuhn and Hellingrath 2002). These can be applied to categorize the impacts of variant-driven variety as these are of course influenced directly. Accordingly, the impacts presented in Table 2 are now being analyzed before the background of these three categories.

Resources: More slack resources to buffer variability are required with the increase of variant-driven variety. The direct impacts include more energy consumption, more part variants, more workers etc. More plant and warehouse spaces are required to accommodate those incremental parts and processes. This leads to more fixed and semi-fixed investments of variety handling systems, such as R&D costs, supply costs, manufacturing and sales costs, distribution

costs. At the same time, more workers and equipment produce more emissions.

Processes: The proliferation of variants may lead to a modification of supply chain process, especially that of the assembly line. In consequence, assembly operations get more complicated and more processes are needed to supply the complicated assembly line, which also contributes to changes of engineering and assembly sequence. Workers have to shift from one variant to another more frequently, which increases the probability of contingencies. More supervision is required in order to monitor and solve the resulting problems in time. In addition, more interfaces between processes, longer lead time and set up time are attributed to the complexity of processes.

Structures: The supply chain structure needs to be changed with the increase of variety and complexity of processes. Firstly, more suppliers and tiers of suppliers are needed to supply more part variants. The lean supply chain aims to cut down the number of suppliers to enhance supply chain efficiency. However, an increase of variants generates the necessity for more suppliers and so complexity and efficiency have to be balanced correctly. And the inventory control policy needs to be adjusted accordingly. Secondly, more and more complex assembly processes imply effects on the in-plants logistics. Line setting, feeding and balancing become more difficult and complicated. Lastly, the management structure of a supply chain has to be prepared to deal with the variability of markets.

All impacts of product variety discussed above obviously contribute to economic, logistics and ecological performance of the automotive supply chain. Consequently, these impacts may be measured by classic criteria comprising logistics performance (e.g. throughput time, customer satisfaction level), costs (e.g. labor costs, warehousing costs) and also against environmental objectives (e.g. energy demand, greenhouse gas emissions) (Cirullies et al. 2011, Klingebiel 2008). The resulting categorization of impacts is summarized in Table 4.

Table 4 - Structure of impacts of variants-driven product variety

	Economic impacts	**Performance impacts**	**Ecological Impacts**
Resources	• More plant and warehouse spaces, • Fixed and semi-fixed investments of variety handling system, • Additional labor and training workers, • More raw materials and part types, • More inventory and safety stocks.	• More coordination effort, • Reduction of profit, • Risks of stockout and loss of major sales.	• More energy consumption.
Processes	• Supervisory requirements, • Increasing transaction, • Increasing overhead costs.	• Increasing contingency, • Longer setup times and lead time, • Productivity decline, • Quality defects, more repairs and rework.	• More emission
Structures	• More suppliers, • More processes, • Changes in the product structure, • Increasing overhead costs, • More costs at retailers.	• Supply chain configuration and inventory control policy, • More difficult in line setting, feeding and balancing, • Complexity in positioning of OPP, • Lower utilization of facilities.	• More energy consumption.

Conclusion

The objective of this paper is to identify and classify influencing factors and impacts of variant-driven product variety in automotive supply chains. First, some basic definitions have been given to specify the research range of this paper, and related literature has been summarized and generalized. Then, both factors and impacts have been analyzed by discussion of several aspects. Factors have been categorized with respect to the main drivers: market, product and supply chain and impacts by three aspects of resources, processes and structures. A categorization of them has been established after discussing the causal relationships between all components.

The study of this paper is the foundation of evaluating and planning variant-driven variety in automotive supply chains. The KPI system will be achieved in the light of the structure of impacts. Future researches will focus on dynamic evaluation, simulation and planning of variant-driven variety. This series of study can help automotive supply chains to discover what the critical impacts of variant-driven variety are, where they originate from and how to control them. It is also helpful to decide how many product variants should be offered to market. Other manufacturing industries can refer to the study to deal with their similar problems too.

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