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Flexibility Challenges in Automotive Assembly, An Approach to Stay Competitive

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Abstract

The undergoing adaptation of mass customization, alongside the development and demand for new power trains, is challenging the manufacturing system of automotive manufacturers. This, in combination with demands from emerging markets and constantly decreasing product lifecycles, calls for increased flexibility. Based on the research findings, key flexibility types for the automotive industry were identified as Mix, New Product, Modification and Volume flexibility. To achieve these flexibilities, the mixed model assembly, modularity and platform strategies are identified as important factors. A generic BOP as part of the platform strategy is central to enable transferring of production.

Keywords

Automotive, flexibility, mixed model assembly, platform, modularity

1. Introduction

The automotive industry is facing one of its biggest manufacturing challenges and changes since Henry Ford introduced the assembly line. As with many other industrial trends, the adoption of Mass Customization is ongoing: customers are requiring unique products, but expect the same quality and price as mass produced products [1]. The demands and regulations from the authorities are also changing more rapidly, making it more challenging for manufacturers to predict what kind of vehicles to manufacture [2, 3, 4]. A recent example of changes in market demands and governmental requirements is the attention on fuel consumption and $C0_2$ emissions that has arisen in the last few years [5]. This has turned the focus towards alternative power trains. Since the Internal Combustion Engine (ICE) has had complete market dominance for over a hundred years, the entire manufacturing system in the automotive industry is optimized for this specific power train. Shifting manufacturing to different power trains will of course challenge the manufacturing system, but perhaps the biggest problem is the fact that it is impossible to predict when or if the ICE will be phased out. The only consensus seems to be that there will be a transition period with many different power trains simultaneously on the market, to include: ICE, hybrid, battery electric and fuel cell vehicles [2]. Therefore, automotive manufacturers need to be very flexible in terms of handling different manufacturing volumes, changing models and the mix of different types of power trains.

For automotive manufacturers to stay competitive they must be agile and prepared for a diversity of power trains. At the same time, they must continue to increase the number of product variants required due to the market demand for more and more customized vehicles, a development that is very likely to continue [2, 3, 6]. This, in combination with the stagnating sales volume in traditional markets such as USA, Europe and Japan, makes it critical to reach profit with smaller volumes [2, 6, 7]. Meanwhile, other markets are emerging, such as Eastern Europe, India and China. These rapidly developing economies may increase their world market share of passenger cars from approx 27 percent in 2007 to 40 to 47 percent in 2020 [5]. It is possible that the product lifecycles will be different in these markets, and that manufacturers can sell discounted models [3]. This will of course challenge the entire organization and operation of automotive manufacturers, but this article focuses on the challenges for the manufacturing system, especially in final assembly, where most of the customization takes place today [8]. What are the key factors to achieve a sustainable manufacturing system for the vehicles of tomorrow? One of the keys to being a competitive automotive manufacturer in the coming century will probably be flexibility [2-4, 8, 9].

2. Aim

This article aims to explore some of the major challenges encountered and describe which types of flexibility are significant for automotive manufacturers to stay competitive, as well as important factors to achieve this.

3. Method

The research presented in this paper is a part of a larger research project called FACECAR: "Flexible Assembly for Considerable Environmental improvements of CARs". The project encompasses nine partners, while this paper is based on semi-structured interviews from two of these, Volvo Cars and SAAB Automobile. The interviews were conducted from December 2009 to May 2010 and were performed face to face, ranging from 30 min to 7 hours, and complemented and verified by telephone and e-mail. The interview respondents consisted of manufacturing experts from Volvo Cars and SAAB Automobile. The authors' own observations were also made during several factory visits to the two companies, observations which were later verified by e-mail.

4. Flexibility

Flexibility is defined as the ability of a manufacturing system to cope with changing circumstances [10] or instability caused by the environment [11, 12].

Kosti et al. (2008) have chosen five flexibility aspects that, in their opinion, are the most relevant for the automotive industry: Machine flexibility, Labor flexibility, Mix flexibility, New Product flexibility, and Modification flexibility. It is assumed for the purposes of this research that Labor and Machine flexibility are means to achieve Mix, New product, and Modification flexibility, therefore Labor, and Machine flexibility are not addressed in this article. Finally Volume flexibility as discussed in Gupta and Somers (1992) was viewed as another key flexibility for this research. In summary the four flexibilities to be addressed are:

- Mix: The number and heterogeneity (variety) of products which can be produced without incurring high transition penalties or large changes in performance outcomes [13]
- New Product: The number and heterogeneity (variety) of new products which are introduced into manufacturing without incurring high transition penalties or large changes in performance outcomes [13]
- Modification: The number and heterogeneity (variety) of products modifications which are accomplished without incurring high transition penalties or large changes in performance outcomes [13]
- Volume: The ability of a manufacturing system to be operated profitably at different overall output levels, thus allowing the factory to adjust manufacturing within a wide range [14]

Flexibility is not new to the automotive industry. GM demonstrated the importance of Product (Mix) flexibility in the automotive industry some hundred years ago. While Ford was producing a single model, GM decided to produce a range of models to fit "every purse and purpose", a strategy which led to GM overtaking Ford's position as industry leader. However, it is important to note that GM did not achieve this flexibility within a single facility [15]. As late as 1997, "flexible manufacturing was unknown in the automotive world" according to Robert Wolf, program manager for International Automotive Components North America [16]. In the article "Ford's flexible future" (2005), Plant Manager Louis Bacigalupo describes how Ford is now able to reuse much of their tooling when changing model by improving the tooling and the system, instead of tearing out the old equipment and replacing it with new. This will decrease downtime associated with model change, and Ford will be able to more quickly adjust to changes in demand [9]. Flexibility is also efficient for better utilization of manufacturing resources, which have been a concern in the automotive industry over the last decades [4]

DaimlerChrysler established their Flexible Manufacturing Strategy (FMS) in 2002. The aim was to enable DaimlerChrysler to build lower volume vehicles and take advantage of market niches [6], something that will become more important to automotive manufacturers in the future [2]. One part of DaimlerChrysler's FMS strategy was to be able to shift manufacturing volumes quickly between different models within a single plant, or among multiple plants [6]. This is made possible by a standardized Bill of Process (BOP), which is one of the cornerstones in the FMS strategy [17]. The Bill of Process defines in what order a vehicle is assembled, for example if the dashboard is mounted before the front seats or vice versa. Multinational automotive companies often have a generic BOP that is used when designing new vehicles. If a vehicle is to be produced in a plant that was not designed to fit the generic BOP, the vehicle might have to be redesigned to fit this certain plant, making it difficult to move or transfer manufacturing to another plant.

Platform strategy reduces development, manufacturing and investment costs, but it also facilitates the manufacturer's ability to quickly respond to changing market needs by reducing development time for new products while improving the ability to update products, and with a limited effect on the manufacturing system [18-20].

In order to achieve flexibility in the automotive industry, three key factors have been identified from the empirical findings and the literature review:

- Mixed model assembly
- Platform strategy
- Modularity

5. Mixed Model assembly

In mixed model assembly (MMA) lines, several variations of a basic design can be assembled in different stages of the same line at the same time. Different vehicle models, for example, can be sequentially assembled in the line [21]. This enables automotive manufacturers to better utilize tooling and personnel, but it also provides the ability to respond to swiftly respond to market demands by adjusting the mix of vehicles, instead of rebuilding assembly lines to facilitate an unexpected high demand for a certain vehicle model. A mixed model final assembly line could also be used to produce vehicles with a mix of different power trains. Incorporating new power trains into an existing final mixed model assembly line is a much smaller investment than building a new, dedicated assembly line for vehicles with the new power train. However, it is challenging to design such a mixed model final assembly line.

Many car manufacturers have made the transition from dedicated final assembly lines to mixed model in recent years. In 2005, BMW merged its two dedicated lines producing the Z3 and X5 models into one mixed model line producing the then new Z4 model and the X5 model [22]. Besides savings due to increased efficiencies in terms of common equipment and processes, incorporating new models into the assembly line will be facilitated [22]. In June 2002, the Vauxhall plant in Ellesmere Port was rebuild to accommodate both the Astra and the Vectra in the same final assembly line [23]. In "Transforming automobile assembly" from 1997, H. Kinutani describes Mazda and how their mixed model assembly line enables them to cope with changes in market and customer needs very quickly. The main driver for this development seems to be the general shift in the automotive industry towards diversified, upgraded and higher quality products [22, 24].

SAAB has been using Mixed Model Assembly (MMA) since 2004 when the 9-5 (1997-2010) was merged into the assembly lines for the 9-3 (2002-present). To enable this merge, the 9-5 construction had to undergo a review. The 9-5 had a much higher workload on the final assembly line and also a different Bill of Process (BOP) than the 9-3. The higher workload was reduced to acceptable levels by using a higher degree of modularization in the assembly process of the 9-5. The differences in workload that remained were balanced in the sequencing of the vehicles on the final assembly line. Some differences in the BOP between the 9-3 and the 9-5 were solved by the construction review, but not all of them, since this would affect the fundamental design of the 9-5 too much. Two examples were that separate stations for dashboard and sunroof mounting had to be built for the 9-5, creating balancing problems and a higher tooling cost. The merge led to better personnel utilization, both for line operators as well as for the supporting and management levels. The continuous improvement work also benefitted from this merge, since it was easier to focus on one manufacturing unit.

Volvo merged its two final assembly lines at Torslanda in 1998 when manufacturing of the new S80 (1998-2006) commenced. The reason for having two dedicated assembly lines was that two different vehicle models' lifecycles could overlap each other. When a new model was to be introduced, one assembly line could be torn down and rebuilt to fit the new model while the other line still produced the older model. Since a vehicle model often has its highest demand in the beginning of its lifecycle, the dedicated line was often under dimensioned in terms of volume. At the same time the other line, producing the older model, could be running at a low output due to low demand, this without the possibility of transferring manufacturing between the assembly lines. As vehicles became more and more advanced the manufacturing equipment they were made on also got more advanced, and thus more expensive. This, in combination with the shortening lifecycles of vehicle models, called for more reuse and better utilization of manufacturing equipment, which led to the merger of Torslanda's two assembly lines.

6. Platform strategy

Most of today's industries want to offer a variety of products based on a well designed product platform [25]. Different automotive manufacturers have different definitions of the Platform concept [18, 26]. However, what most definitions have in common is that they regard the platform as a relatively large set of product components that are physically connected as a stable sub-assembly and are common to different final models [27]. There are also some differences in the terminology regarding platform strategy; sometimes "platform" and "architecture" are used to describe the same thing, for example in the publication Just Auto [28]. In most cases, architecture describes a higher level, i.e. that there can be a number of platforms within each architecture. Some benefits from using a platform strategy are: reduce development and manufacturing costs, reduce development time, reduce systemic complexity and improve the ability to update products [18]. These advantages give an automotive manufacturer the ability to cover the complete market segment by using different body styles and brands of different prestige. Volkswagen, for instance, has a very high degree of parts commonality: 65 % in the case of Golf, A3, Seat and Skoda [29]. Another benefit of a platform strategy is that it also offers advantages for the globalization process of automotive manufacturers by permitting [19]:

- greater flexibility between plants (manufacturing transferring)
- cost reduction through using resources on a world scale
- increased manufacturing system utilization due to higher productivity as a result of reduction of differences

Muffatto (1999) has investigated 4 Japanese automotive manufacturers' definition of a platform. The definitions are divided into narrow, broad and flexible. The narrow definition is defined by its components, and the basic structure is the same for every vehicle derived from it. The flexible definition allows different vehicle lengths, and thereby a greater product flexibility. Instead of being defined by certain components, the platform is defined by the fact that the same stamping dies can be used, though with small modifications. The other important factor is that the same manufacturing lines can be used for every vehicle derived from the platform without major changes. To define a platform in terms of manufacturing process rather than product development might be more interesting for some automotive manufacturers, according to Wilhelm (1997). Depending on how the platform is defined, it accounts for 60-80% of the total development cost of a vehicle [18, 19].

Muffatto (1999) claims that an average of three car models can be derived from each platform. This article, however, was published in 1999, whereas Just Auto's Platform report from 2008 shows that the platform leader Volkswagen, along with Toyota, is producing far more than three models from its A5 platform. Just within the Volkswagen brand, there are more than seven vehicles based on the A5 platform [30]. This would be in line with Muffato's (1999) suggestion that "the overall trend is to reduce the number of platforms" in combination with the fact that costumers are increasingly expecting customized vehicles [2]. Applying a flexible platform definition can reduce the number of platforms to very large extent [18]. In the late 1990s the Volkswagen group, which had around 17 platforms, reduced that number to 4, permitting a market increase in unit numbers per platform [19]. Mahmoud-Jouini and Lenfle (2010) have studied a European automotive manufacturer that in 1998 started working with just 4 platforms. Volkswagen's new platform strategy also focuses on 4 different platforms. The platform that probably will be the largest in manufacturing volume, MQB, will be used in cars ranging from the Polo up to the Passat [28]. This suggests that this platform has a very flexible definition, due to the big geometrical difference of the Polo and the Passat. Mahmoud-Jouini and Lenfle (2010) found that as a result of the European automotive manufacturer platform strategy, product development lead time was reduced by 17 percent, and the numbers of models tripled, moving from one new model each two and a half years to one model each nine months.

Both SAAB Automobile and Volvo Cars have a history as independent companies and as part of a multinational automotive group, GM and Ford respectively. Because of this, they have built vehicles around common group platforms/architectures, and with some common components. This has reduced development costs, but has also meant that their manufacturing facilities have been modified to handle the group platforms/architectures and generic BOP. However, when the companies were incorporated, there was a transition time when their own as well as group-developed platforms were manufactured simultaneously. To facilitate this, the manufacturing system had to be adapted to handle different platform designs. The companies also had to adapt to the platform strategy of their new owners.

7. Modularity

Modularity in production is the ability to pre-combine a large number of components into modules. These modules can then be assembled off-line and subsequently brought onto the main assembly line, to be incorporated into a small and simple series of tasks

[31]. Modularity in the automotive industry is defined as "a group of components, physically close to each other that are both assembled and tested outside the facilities and can be assembled very simply onto the car" [32]. There is a difference between the development of modularity in western and Japanese auto industries. In most cases, western companies focus on Modularity in Production (MIP) in order to out-source production. This approach challenges the link between MIP and Modularity in Design (MID). The Japanese companies, in contrast, strive towards in-house MIP seeking to relate in-house MIP and MID with the main criteria of functionality and conformance quality of modules, assembled on in-house sub-assembly lines [33]. This is crucial to avoid balancing losses when producing different vehicles in different price and size segments.

In 2002, when GM merged its assembly of the Astra and Vectra into one Mixed Model Assembly line, one of the biggest challenges was the work balancing. The Vectra contained 45 min more work content than the Astra, and the vehicles had absolutely no major components in common. The solution to this problem was a complete review of the construction of the Astra, increasing its modularity. Originally it incorporated just 25 modules, whereas the new Vectra incorporated 115. Modularity significantly reduces the line side storage problem, which facilitates the ability of a final assembly line to incorporate different vehicles [23, 24]. The SMART car can be considered the state-of-the-art of automotive modularity. By using a rigid integral body frame/safety cell (called "TRIDION") to which flexible body modules such as doors, front and rear panels and the optional glass roof can be attached, the customers are given the impression of a high level of customization [34]. Due to the modularization, the variations in the manufacturing are kept to a minimum, and lead times are low since the modules are made to stock [34, 35].

Both Volvo Cars and SAAB Automobile have implemented increased modularity in the past years. This is mainly due to the increased complexity in the vehicles, making it difficult to assemble everything on the main assembly line. However, it also facilitates customization, line balancing and optimization of plant layout. If an assembly station has high workload and problems with line side storage, it can be effective to modularize components and move the module assembly away from the line. Modularization can also be used to level out workload differences between products in MMA. This was demonstrated by SAAB in 2004 (discussed in section 5) and GM in the case of the Astra and Vectra models in 2002 [23].

8. Conclusions and discussion

Manufacturing flexibility seems to be relatively new in the automotive industry, but as the customer increasingly demands different models, flexible manufacturing will become more and more important. The introduction of new power trains will further increase the need for flexibility. Decreasing product lifecycles calls for high utilization of manufacturing equipment and a system that is able to efficiently introduce new vehicle models; this ability is referred to as "New Product flexibility". This will make mixed model assembly more important. Automotive manufacturers that have experience in mixed model assembly will probably be better suited for these coming challenges. Mixed model assembly, in combination with a platform and a modularity strategy, will enable automotive manufacturers to have a flexible manufacturing system, something that might become more important in meeting increasingly fluctuating customer demand as well as an increasing demand in emerging markets. These new markets might have different lifecycles, which provide the opportunity to distribute the platform development costs over a larger manufacturing volume. To access these markets, transferring manufacturing to them might be crucial. To enable this, having a generic BOP as part of the platform strategy is important. Since the number of vehicle variants is increasing at a faster rate than total vehicle sales, an increasing number of different models are likely to be produced on the same assembly line. In order to reduce development costs and workload differences, modularity will be important. Modularity will also be important when introducing new power trains in existing assembly systems, since it gives the manufacturers the ability to produce power train-specific assemblies away from the main assembly line; this allows a new power train vehicle to be produced without excessively altering the generic BOP.

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