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DEVELOPMENT OF A QUALITY MANAGEMENT MODEL IN THE AUTOMOTIVE INDUSTRY WITH A FOCUS ON THE QUALITY OF INCOMING PRODUCTS (PART I)

Summary

The automotive industry is one of the main drivers of industrial production and is well known for high-quality criteria. In the past, original equipment manufacturers (OEMs) pushed forward the main processes of new vehicle production. Today, OEM transfers a great deal of high-level engineering tasks to suppliers. As automotive industries are highly automated robot lines, constituting serial production in millions, the smallest error in a delivered product/component causes the downtime for the whole line. In these situations, it is necessary to validate another supplier of the same component, which can last a very long time. This paper presents a quality management model for incoming components in the automotive industry which can recognize possible risks in the early phase of the component prototype development. The model is successfully applied in a company that produces components for OEM, which will be presented in the second part of the paper.

Key words: *supplier quality management, automotive industry, APQP, PPAP, model, OEM*

1. Introduction

The automotive industry works under growing market pressure to develop products faster and to satisfy increasingly sophisticated customer demands regarding quality, cost, safety and reliability; this requires uninterrupted supply chains in the delivery of components. However, the growth in the number of model variants and the use of electronic components and the installation of complex software, with constant pressure to shorten development time and delivery deadlines, have led to an increase in the number of recalls, the most common cause of which are omissions in the quality of parts. In the US alone, the number of vehicle recalls in 2014 was 64 million. Taking into consideration the specific characteristics and challenges of the automotive industry, to comply with quality requirements, the automotive industry sector relies firstly on applying the ISO 9001 standards and IATF 16949 which compliments the ISO 9001 requirements, and emphasizes the use of certain tools and techniques [1].

Due to the great complexity of automotive industry products, it is impossible for certain original equipment manufacturers (OEMs) to possess all the technical expertise and capabilities necessary to develop and manufacture them. Increasingly, OEMs transfer responsibilities for the development and manufacture of certain components to first-level suppliers [2] and are becoming more and more dependent on their suppliers as a result of the great level of outsourcing (for example BMW controls internally about 55% of its research and development and 25% of its share of production, and the rest is left to suppliers) [3]. In the added value of world vehicle production, the vehicle supplier share is showing constant growth, from 56% in 1985 to 82% in 2015 [1]. Production planning processes in cooperation with suppliers result in the reduction of supply and capacity costs and shorter delivery time, which affects the competitiveness of OEMs with regards to quality, costs and innovation [2].

Innovation cycles in the automotive sector are constantly being shortened and an important source of innovation for OEMs are suppliers specialized in certain product categories [4]. In a sector where innovations are crucial, the ability to choose an innovative supplier becomes a competitive advantage [5]. The non-compliance of supplier obligations in time leads to a standstill in production or development, the untimely delivery of vehicles to customers, and thus to significant financial losses [3]. Mitigating the risk of supply chain interruption can be done with a multiple supplier strategy which implies the inclusion of more suppliers in the supply of the same product [6, 7].

The traditional OEM-suppliers relationship implies that OEMs are responsible for the selection, coordination, management and direct allocation of development and production specifications to selected suppliers. In order to reduce the burden on OEMs, there is a trend in the automotive industry to reduce the number of direct (systemic) suppliers. The other suppliers, so-called sub-suppliers, no longer communicate directly with OEMs but with a systemic supplier that coordinates their work. (In four years, Audi halved the number of its direct suppliers of tools) [8]. Outsourcing enables OEM business process optimization through assignment to certain subjects in a supply chain, and even to third-level suppliers [9, 10]. Additionally, this leads to lower costs, higher product quality and more efficient use of resources because every company in the production chain makes its contribution in areas where it has highest expertise [11, 12]. Thus, it is of great importance to focus on the quality of components because in the production chain these components are built into systems, and the whole of the production system runs down to assembly. The quality of products does not depend only on activities related to control and inspection during the production process. Decisions made during product design and in the planning process set the conditions for the development of quality products [13].

The coordination of suppliers is highly important for developing and sustaining the competitiveness of vehicle suppliers, together with the use of production practice based on modularity and delaying the assembly of final products until as late as possible, even to the very moment of the order from a customer in order to decrease supplies and increase income [14]. Some manufacturers, especially of luxury vehicles, make it possible for customers to update the configuration just to several days before the beginning of assembly (e.g. in BMW, vehicle configuration can be updated up to seven days before manufacturing). Logistically, this increases the insecurity regarding the provision of necessary parts and significantly shortens planning cycles for their procurement [15]. The specific practices of supplier quality management (SQM), such as supplier development or supplier integration, often have a positive effect on quality performances [16].

2. Previous research work

In order to respond to the new surroundings and to overcome the above-mentioned problems, new models and concepts of quality management have been developed or the existing ones used in different ways and implemented by OEMs.

With the aim to provide for the high-level quality of components and final products for the automotive industry, several standards were set, such as IATF 16949, CQI standards, and ISO 26262. Standard IATF 16949 is a unique reference model based on ISO 9001, internationally acknowledged by all vehicle manufacturers. It specifies quality system requirements for the design/development, manufacture, assembly and maintenance of automotive industry products [12]. It emphasizes failure prevention, the reduction of process variations, less waste in the supply chain and the application of certain tools and techniques, such as: statistical process control (SPC), failure mode and effects analysis (FMEA), advanced product quality planning (APQP), production part approval process (PPAP), and measurement system analysis (MSA) [1].

Gao et al. [11] proposed the use of the concept of concurrent engineering (CE) in a different systematic way by which barriers between organizational units are broken down. This framework is based on the complexity of products which are developed by OEMs, and, depending on that, proposes different ways to apply CE and suitable tools that are to be used in each case (although it does not give information on how to use the given tools in company surroundings). The model proposes three levels of CE for suppliers. The first level identifies changes and future trends in the product development cycle and the elements of the surroundings. The second level is the basic framework for the implementation of CE with guidelines, where the supplier analyses its strengths and weaknesses, defines improvement projects and runs pilot projects, thus increasing the knowledge of its staff. The third level is directed at the use of certain tools in the CE environment, such as: the design for manufacture and assembly (DFMA), quality function deployment (QFD), FMEA, rapid prototyping (RP), SPC, design of experiments (DoE) and project management techniques.

Beckers et al. [17] presented a model based on a structured approach to the development of vehicle safety, giving for each activity the contribution of the OEM and its supplier that have to work together to define technical safety requirements. The model gives seven steps. The first four steps are the sole responsibility of the OEM, and relate to the technical detail description of all product parts and architecture at the system level and specify technical safety requirements, while the supplier is obliged to deliver to the OEM specific documentation on the interfaces of the components constructed. In the fifth step, the OEM generates the starting set of documents presented as a template that the supplier has to create for its components. Based on the generated documentation, in the sixth step the OEM runs safety analyses and verification of the system design. The last step relates to running the verification of the concept of functional security of a developing system by independent OEM experts.

As the first phase of the product development model, Rozenfeld et al. [12] identified the pre-development phase which encompasses strategic analysis and defining the product strategy. After that comes the phase where the specifications and product concept, design details and production process are defined. Finally, a company evaluates the product performance.

Wlazlak et al. [18] based their model of new product development on automotive industry standards. In the model, supplier workflow is controlled by a quality insurance document which encompasses the requirements of APQP and PPAP. The model has four phases, namely specification, development, industrialization (consisting of pre-series runs and pilot series) and production stages. A supplier has to ensure the compliance of components with the technical specifications of the equipment intended for serial production. Prior to this, the necessary tools and assembly production equipment should be designed and manufactured, and capacity ensured for the production process to start serial production.

The paper "Supplier Quality Management for Component Introduction in the Automobile Industry" [19] focuses on achieving customer satisfaction through the validation of delivered components with "0 ppm" (zero non-compliant products in a million delivered products), that is, the PPAP process. The importance of interconnection between APQP and PPAP processes is emphasized. Besides functional dimensions, what is also highlighted is the importance of the visual presentation of the final product/component, and related to it up to 20% of write-offs of the total write-offs that occur in the production process due to functional non-compliance. Given this, it is necessary to define so-called “border” samples in the phase of prevention quality management (APQP) and the PPAP process. In the error catalogue, the worst error acceptable to a customer is defined. This enables avoidance of production standstill due to the unclear definition of the criterion “what is and what is not acceptable to customers”.

FIAT Automobile and Kyoto University developed a World Class Manufacturing (WCM) model based on ten technical pillars (safety, cost deployment, focused improvement, autonomous maintenance, workplace organization, professional maintenance, quality control, logistic and customer service, early product management, energy and environment) and ten managerial pillars (management commitment, clarity of objectives and KPIs, route map to WCM, allocation of highly qualified people to model areas, commitment of the organization, competence of the organization, time and budget, level of detail, level of expansion and motivation of operators). Each pillar must function in the best possible way and contribute to the quality of the organization’s business. Special attention is given to reducing defects, waste, breakdowns, stock and accidents [20].

The study “Conceptual Model of Management in Automotive Projects” [21] is particularly based on the project phase and the compliance of all functional and specific demands of a customer through the development of samples and final design validation. In the first phase, DFMEA (design FMEA) is done so as to develop the first model of a product/component that confirms the design concept by the customer, so-called “A” samples. In the second phase, PFMEA (process FMEA) is completed, and with it all the risks of the product/component manufacturing technology are analysed, and so-called “B” samples are manufactured; these also have to be checked with the customer in order to move to the final phase of manufacturing, “C” samples. Sample “C” validates the product/component for serial production. This model defines the project phases before component validation, and the importance of the interconnection between certain phases. All additional work on a sample extends the manufacturing time of the final tool that sometimes lasts for up to 40 weeks.

3. Quality management model review

Standardized quality management systems and passed industrial standards present general quality provision requirements, but they do not provide concrete ways to fulfil them in manufacturing businesses. The existing quality management models in the automotive industry are given in a rather general manner, as is the case with the model by Wlazlak [18] whose guidelines on phases were used as the basis of the model. Models often do not encompass all product development and manufacturing phases, or they emphasize certain phases. Companies have the task of establishing a quality management system themselves and of identifying tools and quality methods to be used in it. Besides all standards, tools and guidelines of quality management in the automotive industry, priority is given to specific customer requirements that a manufacturer has to build into a product, and each customer has different needs. Often, situations arise where for a new generation of the same product a customer defines almost completely different specific requirements. They define the whole process of a product (final product or its components), from the preliminary design, through design, prototype, adaptation of certain technologies and the component manufacturing process to achieving safe and stable processes, serial production and quality assurance for as long as a product is used. These very specific customer requirements create the application of specific quality standards for different products. Thus, the focus of this paper is on the development of a general model of quality management in the automotive industry that encompasses important customer requirements and existing automotive industry standards and adjusts them to the specifics of the given manufacturing business and the specifics of the production processes of its suppliers.

The model "Quality management in the automotive industry with a focus on the quality of incoming products" (Figure 1) is presented as a set of phases of product manufacturing, starting with the identification and analyses of customer requirements and the development of a preliminary design, through product development, compliance of characteristics, the PPAP process, the start of production, to the validation of serial production.

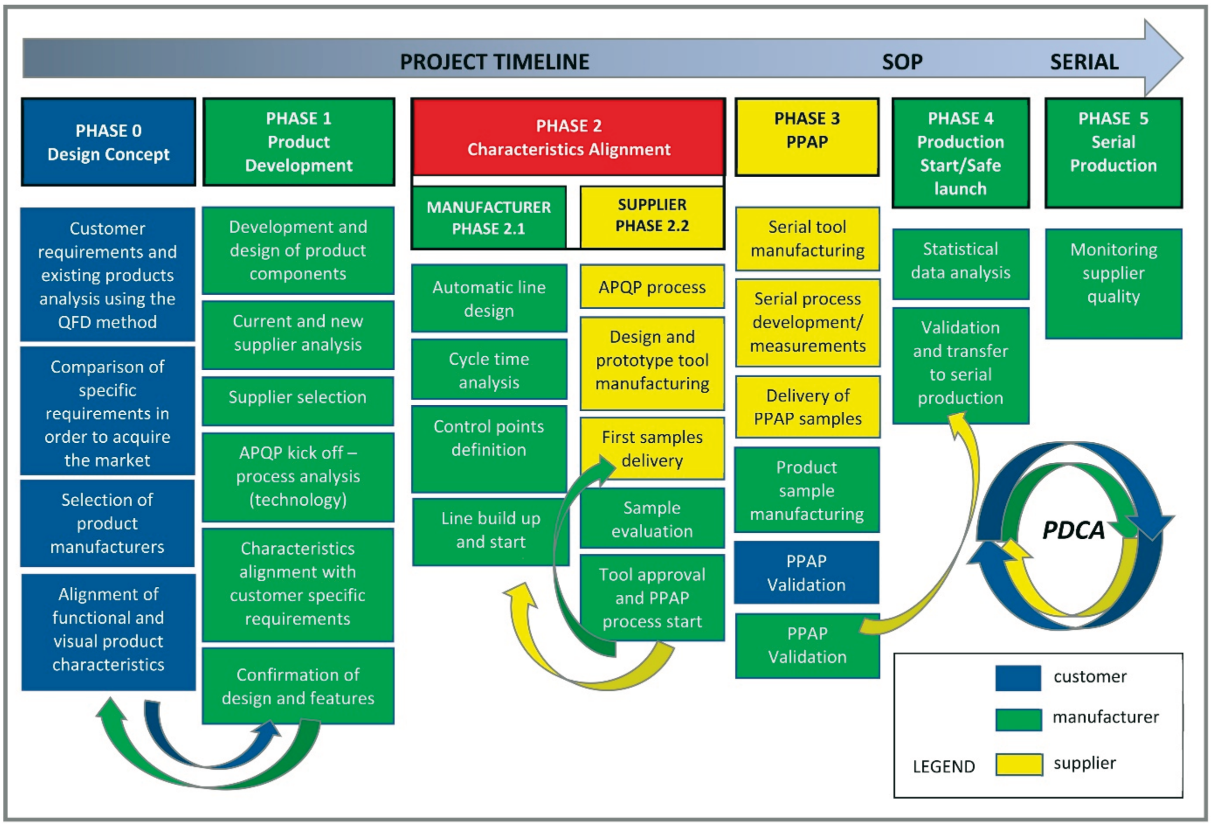

Fig. 1 Model for quality management in the automotive industry with a focus on the quality of incoming products

Quality management should start at the phase of the product preliminary design by the OEM, because in this phase components are defined, and these together with all their characteristics affect the final product functionality and its price. Automotive industry systems consist of a great number of parts obtained from suppliers and then assembled in 100% automated production because these are big series at the annual level. Thus, it is very important that the quality management model focuses on the quality of incoming components and the stability of the supply process. This is why the connections and effects of certain system entrances are very complex, because multiple components produced with different technologies greatly affect the final product and customer satisfaction. Thus, a parallel analysis of all influences runs through a system in which all three stakeholders are involved, i.e., customer, OEM and suppliers of components that are built into the final product.

The model is applicable for the manufacturing of vehicles as final products and for their complex components; the difference refers to vehicle users being seen as customers in the first case and in the second OEM. Detailed phases of the model development follow.

3.1 Phase 0: Development of the preliminary design

The beginning of phase 0 of the model refers to gathering and analysing the wishes and needs of users (customer's voice) that are the basic inputs for new product design. The goal of manufacturers is to make a product that is universally applicable for different consumer groups. In today's modern business, and especially in the application of automotive industry standards, fulfilling specific customer requirements becomes an obligatory precondition to achieve competitiveness on the market. At the same time, it is necessary to fulfil all functional product requirements, have a validation deadline for the first samples, and the start of serial production shorter than competition, with competitive prices. In addition to balancing all the listed market requirements, there is still no guarantee for the full success of the placement of the product on the market, so it is necessary to apply quality planning methods in all product phases, starting with the idea and development to the final delivery. While doing this, it should be borne in mind that price, availability, packaging, functionality, ease of use, durability, usage and maintenance costs, and social standards affect the customer's decision.

In many areas, especially for those who work in the automotive industry, quality is seen as compliance with all the requirements and specifications [19]. By applying the QFD method, customer requirements, which are given as subjective ones (descriptive without clear characteristics), especially in the automotive industry, are turned into measurable technical product characteristics. QFD enables improvement in the negotiation process between the customer/supplier/company, product quality and market success [22]. During its implementation, ecological characteristics should also be kept in mind [23].The QFD method is implemented through four "quality houses" contributing to quality assurance during every phase of the product development process, starting with design [24]. In order to meet the required quality characteristics, production process specifications have to be turned into quality control specifications. These specifications include: component/product control plans, necessary information about the processes that require statistical process control to ensure process stability, preventive machine maintenance, and operational staff training.

Vehicle manufacturers increasingly focus on basic activities such as brand management, engineering, production of some key components and final product assembly, while other activities are transferred to first-level suppliers [25]. The fact that, on average, suppliers in the automotive industry represent 80% of vehicle added value shows their importance. Relevant factors for ranking and selecting suppliers are price, quality, delivery, and supplier reputation. First-level suppliers have a greater likelihood of providing new contracts with the OEM and they show greater technological capabilities, diversified suppliers, suppliers that have the capacity to deliver complete component lines and the capability to produce a great number of components, and suppliers with great exposure to premium brand suppliers. With the aim of managing the supply chain more easily, vehicle manufacturers aim to decrease the number of first-level suppliers [26].

The interconnection of product requirements (especially technical requirements) and their mutual effect on the complete supply chain is crucial. All of these requirements affect product functionality and have to be taken into consideration during analysis and risk assessment. The product should be decomposed into more related production entities that could be assembled after production into one final product with an option to simulate their interactions. Numerous studies have emphasized the potential benefits of the early inclusion of suppliers even in the phase of product concept development [27]. Each project solution satisfies certain functional requirements and each change of project solution changes product functionality. During design, it is very important to take into account tolerance regarding each component, type of material and their interaction in final product use.

Each phase has certain incoming and outgoing parameters that are monitored in order to achieve a controlled quality management system. The essence of the model is the PDCA (plan–do–check–act) cycle in which each phase is thoroughly analysed before moving to another project phase (Figure 2).

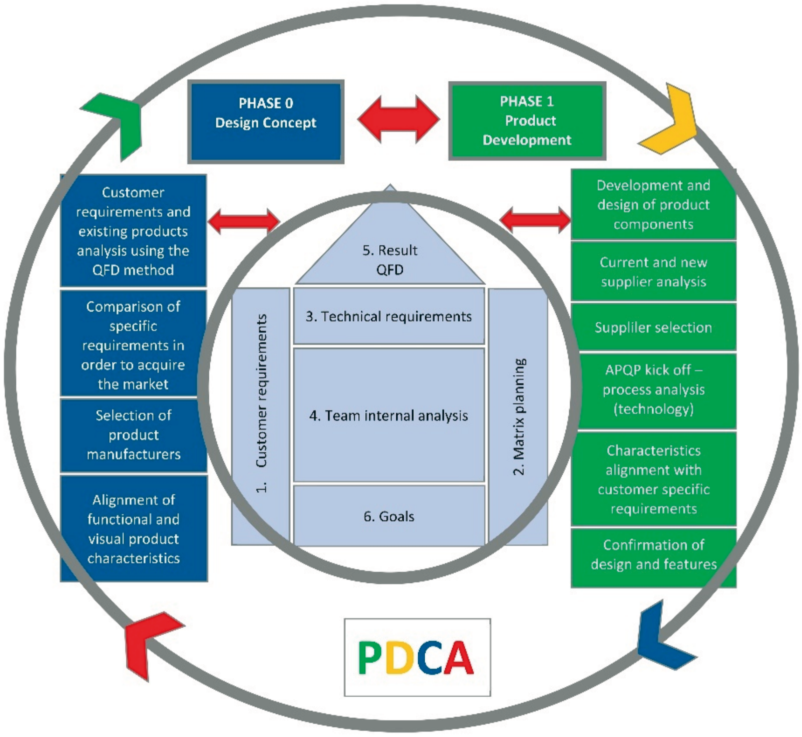

Fig. 2 Interaction of the model (Phase 0 and Phase 1) of the QFD method and the PDCA circuit

3.2 Phase 1: Product development

This is one of the more important project phases and so individual component design and the related manufacturing process are defined here. It is essential to identify risks correctly through PFMEA design based on which each individual component design is developed. Design defines the component design technology which will provide for the development process within the required tolerance and process stability. If the process is not stable for the functional dimensions, then it is necessary to run increased or 100% control which greatly increases the component cost. There are different collaboration relations with a supplier. The supplier can independently produce simple standardized parts or design and produce parts in line with strict customer specifications (OEM/first line supplier). Alternatively, the supplier can have the main responsibility to design components after obtaining the basic specifications from the customer, such as the required size, weight and connection to other parts ("black box" design). Then again, the supplier can have the role of "partner" wholly integrated in the product development and production process [28].

It is necessary to find a second-level supplier for the required characteristics, one that firstly understands the requirements and has adequate technology for the production of the components with balanced cost. Since the deadlines for component prototype production are often very short in order to provide for market delivery of the product ahead of the competition, there is great pressure to select the right supplier and technology in a short timeframe. In the event of a wrong choice, the risk is huge. The selection of a supplier that already delivers similar components greatly reduces the risks, but does not eliminate them. The component procurement risk from a new supplier is higher, but it can ensure components at a better price or even the application of new achievements in given technologies that can give better competitive advantage on the market.

The precondition to even consider a certain candidate as a potential supplier is its certification in line with the IATF 16949 standard. Quality system analyses run an evaluation of potential risks in the following areas: project management, planning and implementation of the product and process development, supplier management, process analysis/production, customer care/satisfaction/service. After a positive result of checking a potential supplier, in the selection process comes a feasibility study approval for the given component (signed by the customer) and the possibility of fulfilling specific customer requirements (e.g. cleanness criteria that specifies the amount and size of metal and non-metal component contamination). These requirements greatly increase the cost of the production process and narrow the number of suppliers. The final selection of the supplier and its final nomination cannot be finalized until a prototype is verified as a proof of customer requirement verification. The first prototype is design verification and the second is the final process and the verification of all dimensions (firstly functional) with harmonization of measurement procedures.

3.3 Phase 2: Characteristics alignment

Phase 2 which consists of two parallel sub-phases sees the start of the APQP process with the selected component supplier, sample production, measuring and the first final product sample production. This phase is the connection between the customer, the final product manufacturer and component manufacturer because adequate feedback is necessary to modify the components and for their production process.

Sub-phase 2.1 encompasses the development of final product manufacturing taking into consideration the production line design, the product manufacturing cycle and suitable component packing which allows for automated component delivery and the building of it into the final product. Production line design implies the development and planning of the automated line for final product assembly where the assembling of different supplier components will take place, as well as the development and planning of the production lines of component production suppliers. Whether the line will be automated, semi-automated or manual primarily depends on the necessary quantities of the given product through the product life span, i.e. through the agreed project duration. In the automotive industry, the existing products are constantly improved in line with customer requirements and market conditions, and thus it is often not possible to produce a new generation of products on the same production line. This all leads to complex production line design with the maximum optimization of production time. One should also consider the possibility of production on more assembly lines.

Sub-phase 2.2. After supplier selection, that is the signing of a contract to produce certain components, based on prototype approval, the APQP kick-off process starts. Through the APQP file, all project phases up to PPAP validation are defined, and through the design analyses (design review) and the possibility of manufacturing, the potential risk analyses and design effect (DFMEA) start. This is especially important if a supplier designs the product according to its technological capabilities. When the customer requirements are implemented (for example through model and technical drawing design), changes are very often harmonized so as to harmonize customer requirements with the technological capabilities of the supplier. If there is any customer requirement that a supplier cannot meet, or if relevant problems occur during the design analyses, the supplier should, with customer approval, undertake appropriate action and document these in a “corrective actions report” in the APQP file. The supplier has to provide a control plan proposal for prototype development which needs to be approved by the customer and completed before the supplier manufactures the first prototype parts. If there is a special requirement of the end customer, that request has to be defined in a drawing for the supplier to use (for example, the already-mentioned cleanness requirements).

In this phase, the supplier must complete the design of its tools, assembly lines and process schedule and define measuring methods and measuring equipment. The supplier should run a process failure mode and effects analysis (PFMEA) based on which suitable production process control plans are developed not only for the development of the prototypes but also for serial production. After the production and adjustment of tools, first of tool (FOT) samples are developed. The supplier delivers the tools and measurement reports to the customer for the tool to be verified. Sometimes a tool has to be verified two or three times through fine adjustment, and the modifications last until the customer verifies the FOT samples.

3.4 Phase 3: PPAP

PPAP refers to component verification and final product verification by the customer for serial production use. This is an obligatory process in the automotive industry and serves to establish trust in the component suppliers and their production processes. This is a process established with the OEM which is further passed through the purchase chain to first and second level suppliers and all other suppliers. With the approval of the PPAP by the OEM, the PPAP can be approved for suppliers (this refers to suppliers of all levels). Often only with greater production can certain process deviations, process instability and non-compliances be found and which could not be foreseen through the PFMEA process. PPAP approval means that the suppliers can deliver the components in serial production conditions.

Validated PPAP samples are products without any allowed variation during the whole life cycle of the product. Each process variation or product variation has to be approved by a customer through the new PPAP process whose scope is narrower that the original. The intention of the submission of the PPAP samples and documentation is to ensure that the supplier understands all the specifications and requirements to ensure the stability and predictability of the process and to reliably deliver products through a harmonized production process. Before sending complete PPAP documentation and initial samples, the supplier has to ensure that all PPAP requirements are fulfilled (given in the AIAG PPAP Reference Manual). The PPAP submission process is based on the approved production drawings. A copy of these drawings (“ballooned” drawings) must be included in the PPAP package. The supplier will also run a PPAP of a sub-supplier, including sub-suppliers that were possibly defined by a customer without a selection option or for a desired sub-supplier, through the suitable control/approval of the PPAP process. The supplier is responsible for filling in all the applicable PPAP documents and sending them to the customer, together with initial samples, in line with the level of PPAP submission. The “cover sheet” of a given PPAP package consists of a signed document part submission warrant (PSW). The level of submission of a PPAP is defined according to the product innovation level, namely whether it is a new product that is validated for the first time, if it is already in use, if it concerns certain changes of a product or processes or if it is a tool for product development, if this product affects the safety of a customer during use or if it significantly affects customer satisfaction or possibly has no effect on customers. Five basic levels of PPAP are defined from L1 to L5 in accordance with which documentation sent to the customer is defined. The customer can request additional information or run a check with the sub-supplier. The supplier must not start any component delivery until the PSW is approved by the customer.

3.5 Phase 4: Start of production

Phase 4 encompasses the start of serial production with intensive component quality follow-up. Production process stability is intensively monitored through the control of functional characteristics and other important production process factors by the manufacturer of the component, but also by the final product manufacturer over a period of three months (*safe launch*). The goal of this phase is the verification of components in serial production conditions. Analyses of data on a weekly basis (gathered according to the control plan approved by the customer for the *safe launch* process) and additional controls and inspections enable identification of non-compliance regarding product quality at a production or assembly location before delivery to the customer. The quality control results are regularly delivered to the customer. After *safe launch* process validation, the supplier can move to the serial production phase. After the start of production (SOP), the supplier must not make any changes in its processes and design without the customer's formal approval.

3.6 Phase 5: Serial production

With the start of serial production, supplier quality monitoring continues regularly. The goal is not only to maintain the existing level of product and process quality, but also to improve it. In the case of complaint, it is necessary to establish a special programme, a so-called "Weak Point Analysis" which analyses in detail the causes of complaint with the use of certain methods, such as the Ishikawa diagram, FTA (fault tree analysis), 5Whys, etc., and defines certain corrective measures. A good strategy is for the customer to periodically (every six months or annually), based on relevant criteria, run a supplier evaluation. If the supplier does not have a satisfactory rating, the customer should make an improvement plan with this supplier.

4. Conclusions

In the very demanding world of the automotive industry there are multiple expectations regarding fulfilling requirements, basic management standards of quality, environment, health and work safety, and standards specific for the automotive industry (IATF 16949, VDA 6.3, AIAG quality tools, CQI). Besides these, it is necessary to fulfil specific customer requirements that are not defined through standards, and which are a priority compared to them. All these interconnections between standard related requirements and specific customer requirements have to be harmonized with existing specific component production technologies, although sometimes new technologies are used in order to gain market competitiveness. New technologies, new suppliers and new projects represent one huge group of risks for successful product market placement and to achieve appropriate market competitiveness. Thus, it is very important to set certain models of process and product quality management in order to minimize risks and unwanted effects. This paper systemizes correct research regarding quality management in the automotive industry with an emphasis on existing process and product management models in the given area. Existing models, although they give many different perspectives for examining the problem of quality management in the automotive industry, are rather general and often do not encompass all phases of the realization of the final product/component. With the use of a systematic approach, an effective and efficient quality management model was developed for the automotive industry for use:

- during the analysis of customer requirements, development, production/assembly or purchase of different components/final product in the automotive industry harmonized with defined customer requirements;
- with the very suppliers themselves in order to reduce the risk of their potential bad influence on the quality of the customer's final product;
- in different business systems in various industries, which should be the subject of further research. This is very important for multiple use product/component development;
- to connect three stakeholders: supplier, manufacturer and customer.

The model was successfully tested in a business system that produces components for the OEM, and the results of the model's use were presented in the second part of the paper (Part II).

Since what is foreseen in the future is the rapid development of systems and component production for autonomous vehicle driving – electric vehicles – the aim for greater driver and passenger safety, quality management models, developed with a systemic approach such as this, will surely be used here. Permanent monitoring and process analysis, and their constant improvement, is the only way to come closer to the goal of zero error (0 ppm).

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