VOL.39 Nº4 2022
https://doi.org/10.2247\MECTA.9487.en

The influence of the state of maturation of components on their approval in new product designs in the automotive industry

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RESUMO: O foco do trabalho é na fase industrialização das peças de compra externa – elaboração das ferramentas, desenvolvimento e construção dos métodos de fabrico e controlos associados. O desenvolvimento da componente / peça é feito pela engenharia da organização: desenhos / ficheiros 3D CAD / normas. O setor de compras da organização seleciona fornecedores para o projeto – através do RFQ / Pedido de Orçamentação. Atraso na maturação do componente (desvios a especificação) e / ou atraso no fornecimento pode resultar em atrasos a jusante, afetando organização e cliente. Também há problemas na performance do componente / produto. A literatura que trata da fase de industrialização é muito escassa não existindo registros de uma fase de industrialização sem sucesso, ou de casos de sucesso, para possível benchmarking entre organizações.

PALAVRAS-CHAVE: APQP. FMEA. DFMA. NPD. Engenharia Simultânea. Benchmark. Factibilidade. Quality Gates. Simulação. Rede de Petri.

ABSTRACT: The focus of the work is on the industrialization phase of externally purchased parts – tooling, development and construction of manufacturing methods and associated controls. The component/ part development is done by the engineering of the organization: drawings / 3D CAD files / standards. The organization's purchasing department selects suppliers for the project – through the RFQ / Request for Quotation. Delay in component maturation (deviations from specification) and / or delay in supply can result in downstream delays, affecting both organization and customer. Also, performance issues in components / products. The literature that deals with the industrialization phase is very scarce and there are no records of an unsuccessful industrialization phase, or cases of success, for possible benchmarking between organizations.

KEYWORDS: APQP. FMEA. DFMA. NPD. Concurrent Engineering. Benchmark. Feasibility. Quality Gates. Simulation. Petri net.

1. Introduction

The increasing pressure to innovate especially on car manufacturers leads to a significantly greater diversity of models and component variants, while development cycles shorten. Consequently, the number of successive series ramp-ups also increases, which poses technical and economic challenges for car manufacturers. These face late or frequent modifications of products and production processes during the series production ramp-up, which hinders timely market launch and causes financial losses. To minimize this, it is necessary to anticipate engineering modifications based on knowledge of product development and through more focused monitoring. With this, the risk of the project reaching the SOP phase without having the necessary maturity level will be reduced. This acquired knowledge will be used to guarantee an adequate level of maturity in the following generations of products [1].

The quality of the final product no longer depends only on its manufacturer, but also on the result of the quality of its components supplied by numerous subcontractors. In the automotive industry, considerable complexity in product structure combined with a high pace of implementation of manufacturing processes created a narrow specialization of suppliers [2].

It is important to understand the role of suppliers/subcontractors in context. In the NPD process, all research and development are done in

the organization, with output drawings, standards and specifications for final products and individual parts. For the individual components it is decided to have outsourcing. All suitable released suppliers for the type of parts considered are contacted to supply them. During the sourcing phase, all suppliers involved check the available documentation to confirm the manufacturing viability of the respective components.

Once the suppliers of the individual components are chosen for the project, the process of developing the manufacturing process in each of them begins. The organization receives samples of the individual parts while the project's maturation phase takes place within the supply chain according to milestones agreed between the parties at the beginning of the project. Each new sampling represents a different maturation state of each part involved. The organization uses these parts to build products and perform the necessary tests for market acceptance of the product. When sufficiently matured and all validation tests show positive results, it is time for the final approval of the status of the parts and the manufacturing processes involved. Then, the start of serial production (Start of Production / SOP) takes place at all suppliers involved. The SOP in the organization occurs later and, consequently, the introduction of the product in the market.

2. Literature Review

The literature that deals with the industrialization phase of components in a new development is very scarce, with no records of how they run for benchmarking between organizations. There are many systematics used in the new product development process (NPD) such as simultaneous engineering (CE), with several associated methodologies (QFD; DFM; DFA; others) in order to have greater knowledge both in terms of market expectations, as well as the manufacturing process. At the planning, management and monitoring level, there is the Advanced Product Quality Planning (APQP) together with the Quality Gates. In addition, it is important to know how to assess whether the tools are well applied / used. For example, there are projects that ended up with delays and cost overruns, where the project's quality gates were not conducted properly at the right time in the project. Therefore, the outcome of the project cannot be clearly predicted in order to implement corrective actions [3].

The new product development phase (New Product Development / NPD) demands new solutions to present more elaborate and, objectively, cheaper products. For this, products must be launched faster and faster and with adequate quality to the structure of the lean manufacturing area. As a result, companies are using a new organizational structure for their new product development processes which, unlike the traditional way, is based on an integrated approach related to concurrent engineering (Concurrent Engineering / CE) where all possible work activities involved are executed in parallel and with all the necessary connections between the activities of the different departments established. The goal is to avoid ongoing setbacks and other issues that arise with the traditional "sequential steps" approach, and thereby improving NPD performance – by concurrent engineering. With EC, the organization tries to speed up the process, increasing its flexibility, adopting a more strategic approach in solving problems through teamwork, developing different skills and improving internal communication. CE refers to bringing in design and production engineers early in the design phase and simultaneously developing the product and the product manufacturing process, i.e., the basic concept of CE refers to taking the product design process out of the isolated world of design engineers and incorporate other functional requirements that have, or should have, influence on the design. With this, it is expected that the application of CE in the NPD process will lead to the development of a better product, easier, cheaper and completed in less time [4].

The Design for Manufacture and Assembly (DFMA) analysis considers the analysis of the product when it is disassembled and assembled again,

evaluating the time and costs of moving and joining components. The DFM methodology refers to the simplification of product manufacturing, while the DFA methodology has its focus on product simplification as well as cost reduction. The DFM is used to assess the feasibility of product industrialization by addressing all related issues (e.g., material and machine/tool selection, manufacturing methods, process planning, assembly, quality control testing, and others) for product development to ensure that the design features can be manufactured as easily as possible. DFA addresses assembly quality in large part by simplifying the product structure and reducing the total number of parts in a product [5] [6] [7].

It is observed that most of the procedures and methodologies presented in the bibliographic review are focused upstream of the industrialization process, although the feasibility analysis is still in the quotation phase; APQP such as Quality Gates (QG) and early supplier involvement are relevant.

Advanced Product Quality Planning (APQP) is one of the quality management system tools required by the ISO/TS 16949 standard used in the automotive industries. The methodology considers five steps: planning, design of the management system, definition of control methods and approval of the management system, critical analysis and improvements. The application of this methodology allows the identification, analysis and control of risks. Currently, the APQP is a mandatory requirement for delivering products to companies in the automotive chain, as it works as a guide in the development process and also a standard for analyzing results between suppliers and the organization [8]. The APQP process is defined in the APQP manual of the AIAG (Automotive Industry Action Group), a non-profit association of the automotive industry founded in 1982.

Some advantages can be obtained with the use of APQP, among which stand out the early identification of necessary changes in the product and process and the development of the product on time, with lower cost and with attention to the customer's requirements. The first step in product quality planning for the automotive industry is the selection of an APQP project owner followed by a cross-functional team composed of representatives from production, engineering, quality, logistics, human resources, health and safety, asset security, sales, purchases, after-sales assistance, also suppliers and customers, if applicable. A cross-functional APQP team, in the initial phase of the program, should meet to define: (a) the roles and responsibilities of each process represented; (b) a timeline for the five steps of the APQP process; (c) the costs that must be considered. It is recommended that the APQP team consider applying "concurrent engineering" to speed up the project, activities should be carried out concurrently, to avoid unnecessary delays. During the implementation of the project, the team will face problems. It is the responsibility of the APQP team to establish a disciplined approach to problem solving – for example: benchmarks, PDCA (Plan, Do, Check, Act), cause and effect diagram, process flowchart, FMEA (Failure Mode and Effects Analysis) and record the problems [4].

Benchmarking [9] is the search for best practices that lead a company to maximize business performance. It is also the ongoing process of measuring products, services and practices against the strongest competitors or companies recognized as leaders in their industries. Benchmarking leads to understanding a competitor's position, but not to creating practices beyond those of the competition, these will only be achieved.

Failure Mode and Effects Analysis (FMEA) is a method for detecting potential product failures as early as possible in the development process. This enables improvement in product quality with a consequent decrease in customer complaints and minimization of costs related to these complaints [10]. It was started in the 1940s by the US military and is a step-by-step approach to identifying all possible flaws in a design, a manufacturing or assembly process, or a product or service. "Failure modes" means the ways, or modes, in which something can fail. Faults are any errors or defects, especially those that affect the customer, and can be potential or ac-

tual. "Effects analysis" refers to studying the consequences of these failures. Failures are prioritized according to the severity of their consequences, the frequency with which they occur, and the ease with which they can be detected. The objective of the FMEA is to take actions to eliminate or reduce failures, starting with the highest priority. Failure modes and effects analysis also document current knowledge and actions on failure risks, for use in continuous improvement. FMEA is used during design to prevent failures. Later it is used for control, before and during the continuous operation of the process. Ideally, FMEA begins during the early conceptual stages of design and continues throughout the life of the product or service.

Quality Gates were initially applied to product development processes, especially quality control in the automotive industry. Since then, Quality Gates has been applied more widely to quality assurance and project management and has been successfully applied as a quality assurance mechanism in various industries [11]. The Quality Gate procedure results in a pass/fail decision to move forward, based on a set of pre-determined exit criteria for each phase or milestone being verified. However, the Quality Gate criteria can also include the success of other Quality Gates so that the Quality Gates can be interconnected with each other [4]. Quality Gates can also serve as a synchronization point for process results, and entry and exit criteria must be met before the product can continue through the process. Quality Gates help break down overall process end result requirements into sub-goals for single process steps and clarify internal process chain dependencies. Furthermore, Quality Gates doesn't just have to run serially, it can run in parallel as well. That is, different subprocesses are executed independently, but at some point, they are filtered together, as the products of one phase are used as inputs for the next phase [4].

When incorporated into APQP, quality gates are performed at the end of each APQP phase, formalizing the passage from one APQP phase to another. This combined systematic can act both at the level of the organization and at the level of suppliers.

On early supplier involvement (Early Supplier Involvement / ESI) we have the contribution of Eisto and his colleagues [12] who present their point of view on the levels of collaboration between organization / supplier. Starting with the "Order Delivery Level" (Level I) in which an organization engages a vendor when the project is ready. The first contact is usually a quote request with the part design and the related components are usually frozen. Only small changes are possible, for example: adjusting the wall thickness or adding some details to facilitate the manufacture of parts – in case of castings. The organization sends a request for quotation to several suppliers and compares the quotations for a final decision on the chosen supplier. The customer only provides a drawing and delivery date for the part to the suppliers. ESI is not really used at this level of collaboration [12].

Now, the "Cooperative Level" (Level II) refers to where the organization and vendor processes are partially overlapping where all participants cooperate on design. Suppliers have a chance to comment and rate the part design before it is frozen. This allows for changes in the design of parts that facilitate the manufacturing process. Contracts become more important at this level as suppliers are now improving the design of the organization's components and using their own resources for this improvement [12].

Considering the "Partnership Level" (Level III), suppliers are chosen at the beginning of a project and the processes are completely superimposed. This allows focusing the expertise of each supplier on the organization's project at the right time [12].

This level is suitable for complex parts and/or parts that play an important role in the final product. Rather than choosing the lowest bid, partners collaboratively develop new value-added solutions. When inventing new solutions, the opportunities for reducing costs and time are much greater in the long run of manufacturing than by price competition, also considering the optimization of the product and the production chain [12].

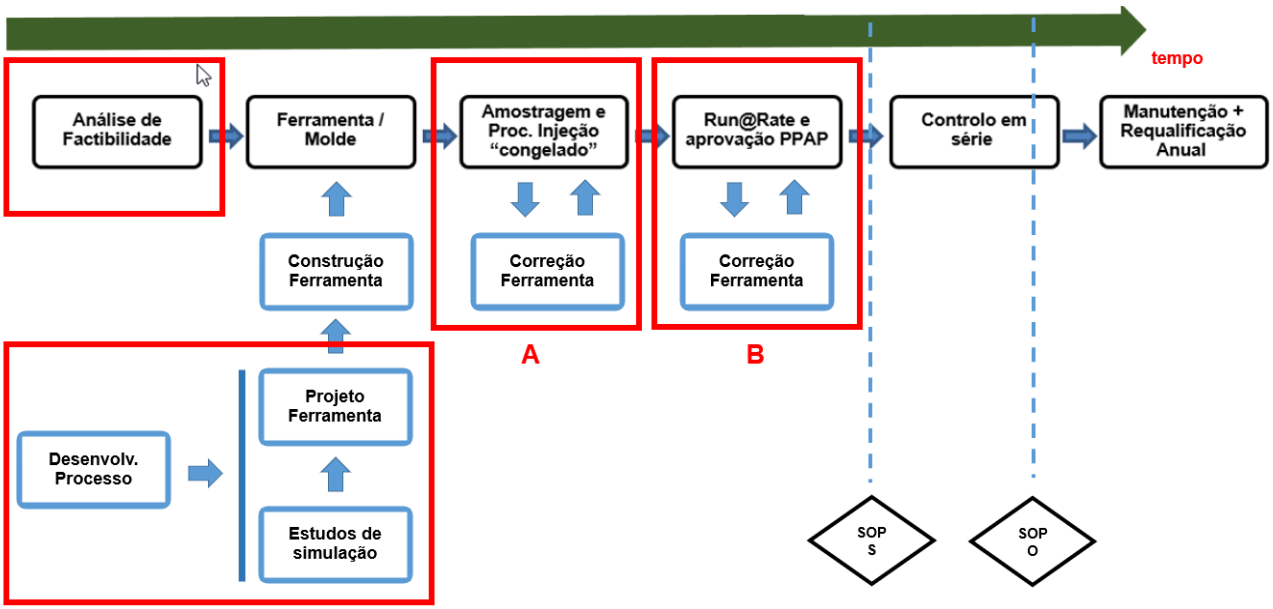
There are other challenges to successful "early supplier engagement". The main principle of an effective ESI refers to having a detailed and comprehensive specification available in the early stages of the project [13], because it helps (1) to know the exact means needed (equipment and human resources) that will be needed and (2) allow a feasibility study.

Another point is related to the validation of the tool project. Leaving the tool design in the hands of the supplier without any verification by the organization is risky, especially when the whole process is based on the knowledge of the supplier chosen for the part – by type of part / type of material – without any feasibility analysis more robust, applying more suitable simulation software [13].

The advantage of simulations – which is an example of a collaborative approach between organization and suppliers – is to try to gain a better understanding of the possible results of part filling (defects and locations) through the interpretation of simulation results. Cases of excessive turbulence, air/gas entrapment and/or early solidification (unplanned) during filling can compromise component quality as well as the performance of the final product. With this, modifications can be suggested in the design of the part or in the concept of the manufacturing process / tool. This is effective when it occurs early in the project and changes are allowed before the status freeze. When it happens after the design freeze, especially when the part is formally supplied, the possibilities for adjusting process parameters are limited and the opportunity to improve manufacturability is lost. Product cost structure can be easily defined when it occurs at the beginning of the development process The other situation refers to possible / future design changes, for example: adding / removing geometries to the existing part design. This alters the flow patterns that can give rise to another range of defects - surface defects / internal defects - which can also cause a reduction in mechanical properties, sometimes localized. This requires a redesign of the manufacturing system, with previous studies by simulations [12].

In case of any failure in the advanced phases of the product design, it can represent delays and even failure of the project. There is no time avail-

Fig. 1 - Modeling: Plastic injection process - Simulation Framework



able to fix, modify or even build a new tool [13].

Taking as an example a mechanical component made of plastic material manufactured through the injection process acquired from an external supplier, it is possible to present the entire maturation process of the component design still in the simulation phase with the support of the supplier. This demonstrates the need for alignment and synchronization between organization and suppliers [14].

This work presents a framework and a simulation model to study the maturation of components and results that demonstrate the usefulness of this process.

3. Framework For Simulation

For this project of plastic part by injection process, a simulation of the manufacturing process was carried out. For this project of plastic part by injection process, a simulation of the manufacturing process was carried out. The steps in the boxes "in red" are the most critical. The feasibility analysis and the development of the manufacturing process influence the tool concept and, consequently, the number of tool interventions for dimensional correction. The steps related to tool intervention for dimensional correction were divided into two phases – phase A and phase B. In phase A are the intervention loops required until we have an acceptable dimensional part for series production and thus advance to the submission phase of PPAP. In phase B, there are the "extraordinary" tool intervention loops, not expected for the project phase resulting from reliability tests carried out on the final product.

4. Simulation Model And Results

For simulation purposes, a discrete event dynamic system model can be defined for this analysis, being composed of entities, activities and processes. Each system component that requires an explicit representation is an entity [15] [16]. The objective of the simulation is to reproduce the activities of entities in the model and draw conclusions about the behavior and performance of the system [17] [16].

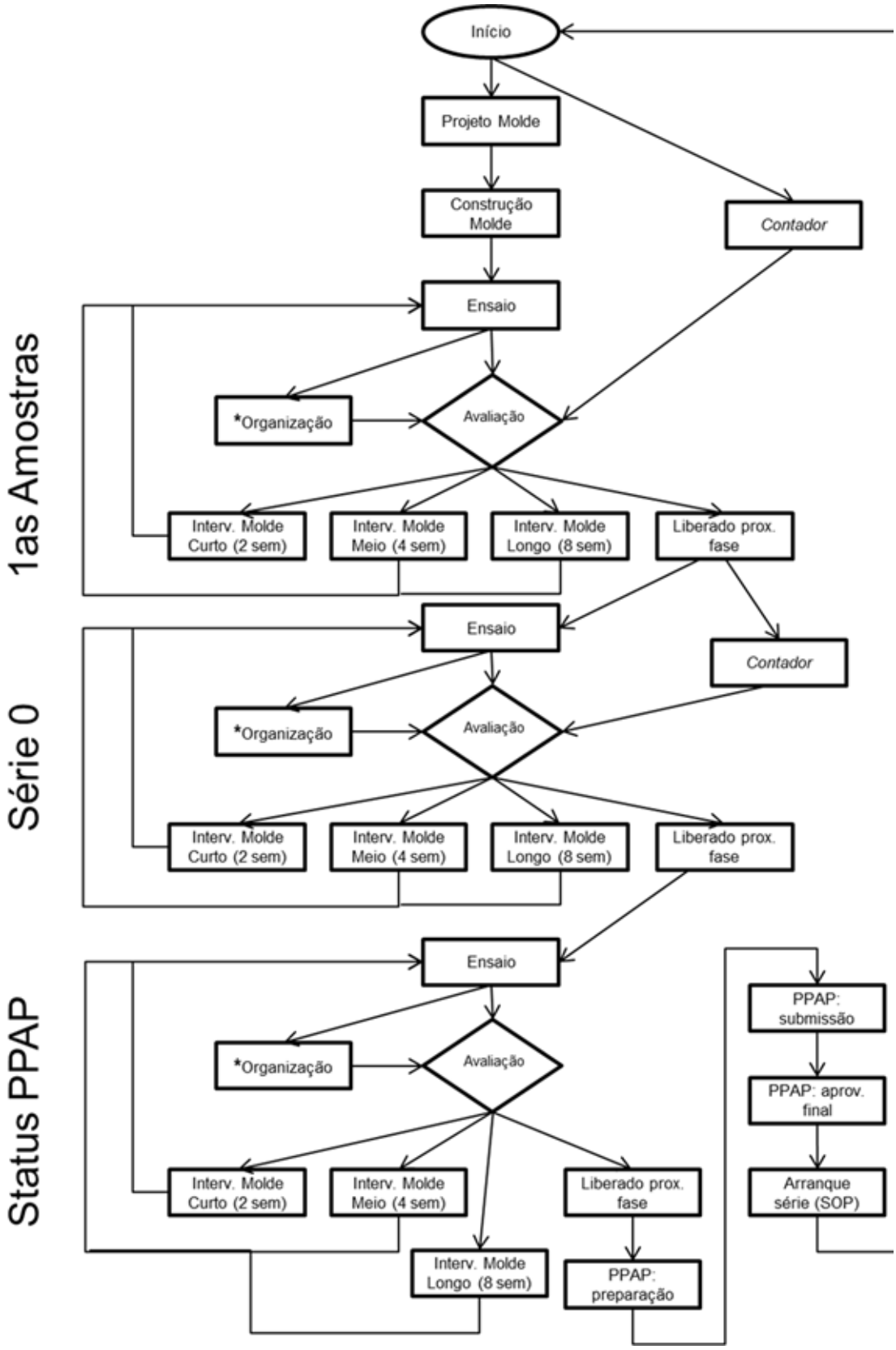
This class includes all simulation tools based on mathematical formalisms that model dynamic discrete event systems such as automata, Petri nets, Markov chains and others [18] [16].

The theoretical aspect of Petri nets allows accurate modeling and analysis of the behavior of the system, while the graphical representation of Petri nets allows the visualization of changes in the state of the modeled system [19].

The simulation model for building the Petri net is shown in Figure 2. The modeling shown in figure 1 is adequate for the existing processes in most organizations – considering the phases of 1st samples, series 0 (or pilot series) and finalization of the manufacturing process at the supplier, called PPAP status. The phases of 1st samples and series 0 correspond to phase A of figure 1, while the PPAP status corresponds to phase B. In the model of figure 2, the cycle of tool interventions has been considered for each phase, with duration options depending on the complexity of the intervention.

Returning to our project of a plastic injection part: a project of a plastic injection part of thermoplastics, with dimensions of 160 X 298 X 25mm and with holes. The tool will be single cavity; size of 1100 X 1200 X 850 mm, considering moving elements. In addition, the tool will have 3 plates, hot runner and subsea injection. The tool project to be developed will consider the use of a 400-ton injection molding machine (closing force) and will take up to 4 weeks, with customer approval. The time required for construction would be 16 weeks for the first trial. Interventions for dimensional correction are classified into: (a) Simple interventions – up to 2 weeks, consisting of removing burrs, adjusting gaps (visual / functional) and correcting dimensional deviations up to 0.2mm; (b) Interventions of medium complexity – up to 4 weeks, consisting of design changes with welding in the bushing or cavity (with the manufacture of new electrodes) and exchange of inserts, slides, rocker arms and (c) Complex interventions – between 8 and 10 weeks , consisting in the construction of a new cavity and/or bushing.

Fig. 2 - Model for simulation



The ideal conditions considered by most suppliers of this type of technology in their budgeting are the following: 2 to 3 simple "2 weeks" interventions, with a maximum of 1 medium complexity "4 weeks" intervention. In the 121 simulations carried out in the Petri Net, the following results were obtained in terms of the number of interventions: (a) 1st samples: It took 8 to 9 interventions, simple / medium / complex; (b) Series 0: It took 8 to 9 interventions, simple / medium / complex; (c) PPAP Phase: It took 4 interventions – at most 1 medium intervention / 4 weeks.

In terms of the duration of each phase of the project, we have the following figures: (d) the samples: 28 to 36 weeks; (e) Series 0: 28 to 36 weeks; (f) PPAP Status: 1 to 15 weeks and (g) Full Simulation: 77 to 107 weeks. Taking as a basis for comparison that under ideal conditions the total duration of the project would be 30 weeks, this increase between 47 and 77 weeks is very serious for the deadlines agreed with customers, culminating in delays in the start of series production downstream of the supplier – affecting organization and end customer.

5. Conclusions

It is observed that most methodologies evaluated in the literature review do not focus on feasibility analysis and simulation studies.

An important point: if a part is not OK in the feasibility analysis and simulation studies, it certainly will not be OK near the SOP. A poor feasibility analysis results in "real" parts out of specification". The same is true of the untreated NOK points from the simulation studies. Dimensional correction in "real" parts results in a huge effort, resulting in numerous "long" and "complex" interventions, whose results are not "as efficient" if they were still treated in the tool design already prepared for "complex" interventions (such as "safety steel").

Additionally, due to the total duration of the project observed in each of the simulations performed, it is important to bear in mind that the project will probably start serial production with the parts not yet reaching the maximum maturity of the part / component and the manufacturing process. As a result, the organization will be using parts with different design statuses – with its suppliers still working in the pilot series or pre-PPAP phase.

This can cause problems for both the supplier and the organization. The supplier still has its engineering team to handle the part until it has the final PPAP approved, manage the engineering/design levels of the part to be shipped to the organization to avoid any mixing of different statuses of different parts. This may entail risk and therefore the organization must take care not to affect the performance of the product to be delivered.

Therefore, it is important to define the strategy for how NOK points will be treated during the project.

Greater involvement of suppliers in design development (eg: DFMA) using appropriate simulation tools helps to increase its feasibility and the robustness of the manufacturing process.

Finally, the APQP and Quality Gates should focus more on suppliers, as well as the Quality Gates in the organization that should question the maturation, monitoring the evolution of the maturation of the component in the suppliers.

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