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Resumo Nowadays, companies aiming to survive in the automotive industry must reinvent themselves by investing in technological innovation and addressing the all-important product quality. This work focuses on the industrialization phase of externally purchased parts, more specifically on the development and construction of manufacturing methods and associated controls. Most methodologies on the market today do not focus on the negative points resulting from both feasibility analyses and simulation stud...

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The influence of the maturation status of components on their approval in new product design

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Abstract. Nowadays, companies aiming to survive in the automotive industry must reinvent themselves by investing in technological innovation and addressing the all-important product quality. This work focuses on the industrialization phase of externally purchased parts, more specifically on the development and construction of manufacturing methods and associated controls. Most methodologies on the market today do not focus on the negative points resulting from both feasibility analyses and simulation studies, such as delays and lack of proper maturation for start of series production, highlighting the need to further advance process efficiency by using continuous quality improvement tools. A simulation of a manufacturing process in an automotive environment using a Petri net-based simulation model was used. Results show that for a generic Production Part Approval Process (PPAP) model there is a delay of 47-77 weeks in project maturation that can compromise a robust start of series production on the client. The main objective of this work is to show that is possible to increase both the feasibility and robustness of the manufacturing process without delays when the project management considers a stronger supplier's involvement in the design development phase and by applying more focused Advanced Product Quality Planning (APQP)

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and Quality Gates (QG) on monitoring the project evolution at suppliers and organizations. Further studies should be carried out to evaluate the impact of other variables such as introducing a wider variability to the maturation phase as well as other impacting variables.

Keywords: APQP; New product development; Feasibility; Quality gates; 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. But this is not observed especially in terms of purchased parts to be integrated in the final product assembly by main organizations. Purchased components with several delays during sampling phase and compromising an maturation required to adequate performance of final product to be commercialized. To minimize this, it is necessary to anticipate engineering modifications based on knowledge in product development and through more focused monitoring. With this, the risk of the project reaching the production start-up phase (Start of Production / SOP) 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]. 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 maturation phase of the project takes place within the supply chain according to the deadlines agreed between the companies at the beginning of the project. Each new sampling represents a different maturation state of each reference involved. The organization uses these parts to build products and perform the necessary tests for market acceptance of the product. When sufficiently matured and with all validation tests showing positive results, it is time for the final approval of the status of the parts and the manufacturing processes involved. Then there is the Start of Production (SOP) at all suppliers involved. The SOP in the organization occurs later and, consequently, with the introduction of the product in the market.

2. Background for New Product Development

The literature that deals with the industrialization phase of components in a new development is very scarce and there are no records of performance results. It is observed that most of the procedures and methodologies presented in the literature review are focused upstream of the industrialization process.

In this section, a short review of how new product development (NPD) is carried out in the automotive industry, especially with the use of the concurrent engineering (CE) to support for an efficient realization, is presented. Moreover, systematics for better planning and monitoring of project maturation such as Advanced Product Quality Planning (APQP) and Quality Gates (QG) [3] and simulations are also addressed.

Products must be launched faster and faster and with adequate quality. As a result, companies are using an organizational structure for their new product development processes which, unlike the traditional way, is based on an integrated approach related to concurrent engineering (CE) where all possible work activities involved are performed in parallel and with all the necessary connections between the activities of the different departments established. With concurrent engineering (CE) [4], the goal is to avoid ongoing setbacks and other issues that arise with the traditional "sequential steps" approach, and thereby improving NPD performance. But it is important to have a consequent planning of all tasks required for project realization are considered with own deadlines, responsible and connections to other tasks – planning like Advanced Product Quality Planning (APQP). It is one of the quality management system tools required by the IATF 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 a standard for analysing results between suppliers and the organization [5]. But this alone, without monitoring and evaluation of the output of each task realized and time for realization does not help to prevent the obstacles or solve them in short time to prevent project delays. For this, tool like Quality Gates (QG) are used. Quality Gates were initially applied to product development processes, especially quality control in the automotive industry. Since then, Quality Gates have been applied more broadly to quality assurance and project management and have been successfully applied as a quality assurance mechanism in various industries [6]. 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 [4]. 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 outcomes of part filling through interpretation of simulation results. 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 [7].

3. Methodology

The methodology considered for this work consists of preparation of a simulation to be used to show the potential risks on project realization caused by the weak feasibility analysis and simulations performed without treatment of negative points detected and, finally by no effective monitoring on projects evolution at supplier through quality gates from organization. First, it is presented the critical points in a development flow for a plastic part being realized at a supplier, which was awarded by the organization for this component. Then, it is prepared a framework contemplating the required main manufacturing phases, such as first sampling, series 0 (pilot phase) and PPAP status (Production Part Approval Process). It is used to create a simulation model based on Petri net and run simulations of all possible scenarios for the complete project realization and count the number of iterations done on tools until a maturation is acquired for PPAP submission release and the time required for passing each project phases and for the whole project.

4. Framework used in simulation

For this project of purchased component – in this case, a plastic part by injection process – a simulation of the manufacturing process was carried out. Figure 1 shows the development flow of the manufacturing process at the supplier. The steps in the red boxes are the most critical.

The feasibility analysis and the development of the manufacturing process influence

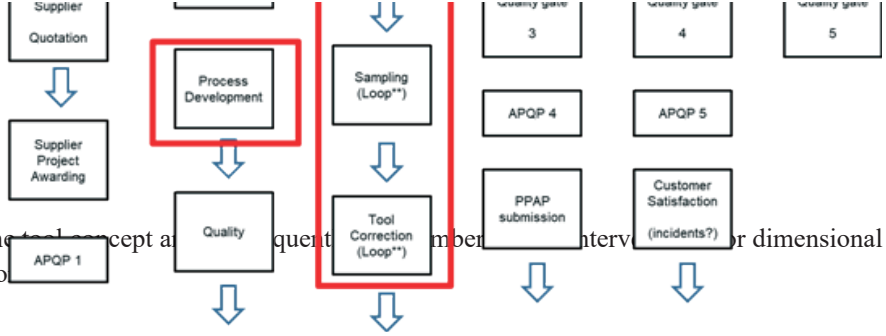

Figure 1. Example of development flow of the manufacturing process at the supplier

The steps related to tool intervention for dimensional correction were divided into two phases – phase A and phase B (see Figure 2). Phase A includes the intervention loops required until we have an acceptable dimensional part for serial production and thus advance to the submission phase of PPAP. Phase B includes the "extraordinary" tool intervention loops, not expected for the project phase resulting from design verification / product validation tests (DV / PV tests) carried out on the final product.

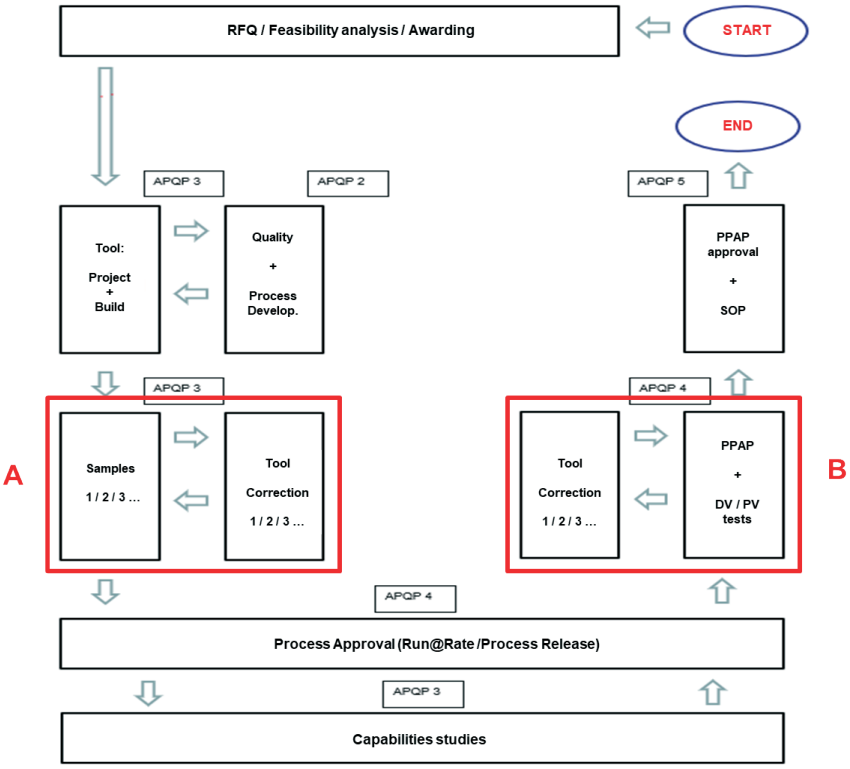

Figure 2. Development flow of the manufacturing process simplified with phases A and B

In Figure 3, it is possible to see the same development flow of the manufacturing process now considering time and taking in consideration two additional milestones: Start of Production at supplier (SOP S) and Start of Production at organization (SOP O). SOP S happens before the SOP O. It is expected that the whole process at supplier is concluded and PPAP released – the component (or sub-assembly or others) has achieved a maturation level that assures the proper functionality of the component and the final product delivered to end consumer by organization.

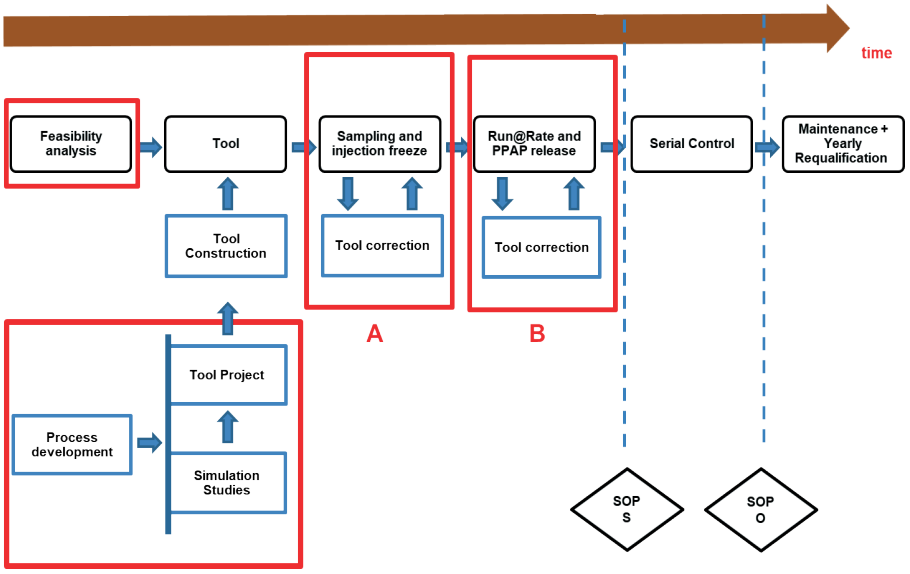

Figure 3. Development flow of the manufacturing process simplified considering "time".

5. 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 [8,9]. The objective of the simulation is to reproduce the activities of the entities in the model and draw conclusions about the behaviour and performance of the system [9,10].

This class includes all simulation tools based on mathematical formalisms that model dynamic systems of discrete events such as automata, Petri nets, Markov chains, others [9,11]. The theoretical aspect of Petri nets allows accurate modelling and analysis of the system's behaviour, while the graphical representation of Petri nets allows the visualization of changes in the state of the modelled system [12].

The simulation model for building the Petri net is shown in Figure 4. The modelling shown in Figure 2 and Figure 3 are suitable for existing processes in most organizations - considering the phases of 1st samples, series 0 (or pilot series) and completion of the manufacturing process at the supplier, called the PPAP status. The phases of 1st samples and series 0 correspond to phase A of Figure 2 and Figure 3 (phase A1 and A2), while the PPAP state corresponds to phase B.

In the model of Figure 4, the cycle of tool interventions for each phase has been considered, with options for the duration of the even depending on the complexity of the intervention. Returning to our project of a plastic injection part: a project of a plastic plate by injection process using thermoplastics (using Acrylonitrile Butadiene Styrene, or ABS plastic), 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 for some lateral details / features. In addition, the tool will have three plates, hot runner, and submarine injection.

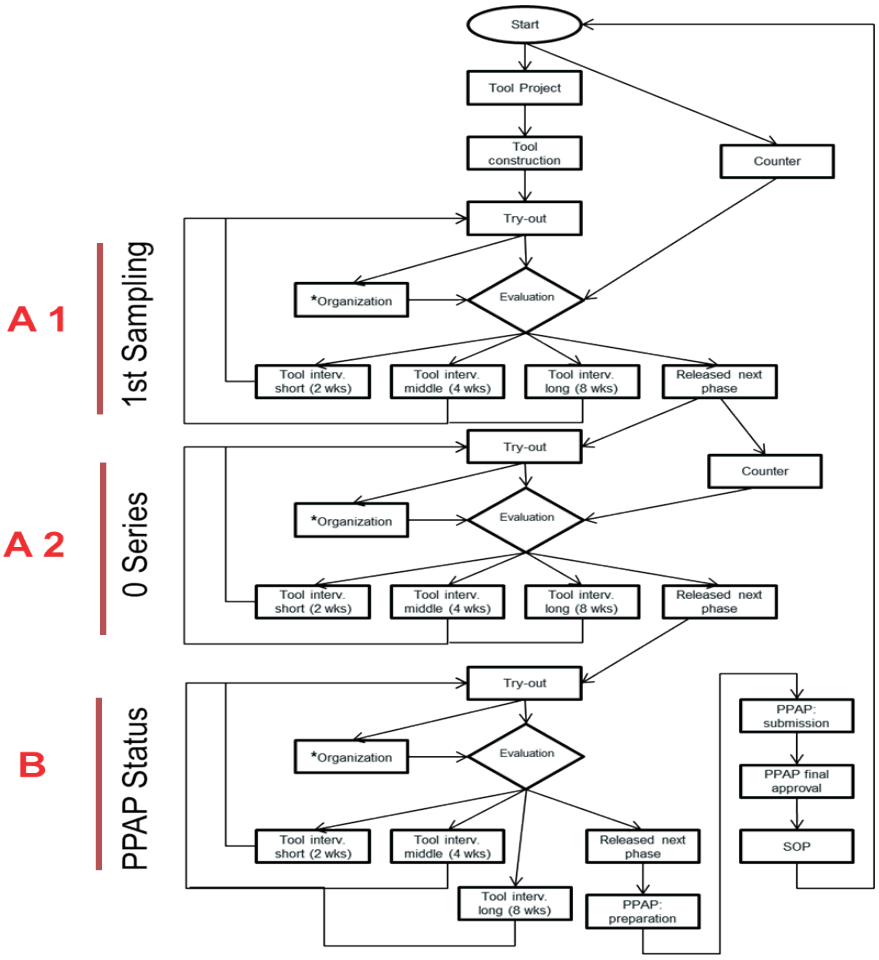

Figure 4. Simulation model

The tool project to be developed will consider the use of a 400-ton injection moulding machine (closing force) and will take up to 4 weeks, subject to customer approval. The time required for construction would be 16 weeks for the first trial.

There is no fixed number of tool interactions and time needed for each one. It is related to the number of Out-of-Specification dimensions and the complexity involved and, also, the effort required for that.

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 tool cavity and/or tool core.

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: 8 to 9 interventions were needed, simple / medium / complex; (b) Series 0: 8 to 9 interventions were needed, simple / medium / complex; (c) PPAP status: 4 interventions were required – maximum 1 average intervention / 4 weeks. In terms of the duration of each phase of the project, we have the following values: (d) 1st 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, a delay between 47 and 77 weeks is very serious for the deadlines agreed with the customers, culminating in delays in the start of serial production downstream of the supplier – affecting organization and end customer. This needs to be the focus / target of any improvement action.

It is important also to correlate the reasons for appearing the need of "4-weeks / 8-weeks interventions" with the project phase. In case of interventions during 1st sampling, it corresponds to the "points raised in the feasibility analyses that became "non-conformities" in the real parts. If happens in Series 0 and/or PPAP phase, it is related to negative results in reliability tests performed on the part or the final product already in the end of project (already in PPAP submission phase).

Now, in case high number of interventions yet in series 0, this refers to the output of larger production lots (at supplier / at organization) that show weak points in the manufacturing process at supplier.

6. Conclusions

Organizations today, especially in the automotive industry, need to bring innovative new products to market earlier than competitors to build market. Required NPD when associated with new technologies requires organizations to evolve to meet all customer/end user requirements. Customer satisfaction through meeting deadlines with products with maturity and quality is one of the main objectives of an organization.

As observed in previous sessions of this work, delays between 47 and 77 weeks to get a matured component to be integrated in final product to be delivered to an OEM is going in opposite direction of what is planned and expected.

Depending on how concurrent engineering is embedded within the organization when designing the product and process through collaborative processes with all stakeholders – suppliers / organization / customers – it aims to minimize the occurrence of problems during mass production in the organization. One of the goals is to collect all open issues and close them before production starts (SOP). The goal now is to work towards "lean production", especially the automotive industries, to be faster and more accurate. Even more important when the organization works with the "lean" philosophy, in which the whole process must be "tuned", everything must be "available" in terms of quantity and quality. Any interruption is very penalizing for all interested parties.

As previously observed, a feasibility analysis is a very important point to assure a product with quality. Poor feasibility analysis will result in "real" parts being out of specification. Then, the topic follows to the simulation studies. It is not only to realize a simulation study, but to know what is done after having the results, especially the negative ones, like excessive warping, and visible welding lines. It is important to know, in this earlier phase, the consequences on the parts dimensions and discuss / agree strategies between supplier chain and organization development – changes in part design and / or tool concept to, at least, minimize this. To sum up, simulation studies with negative aspects will result in "real" parts out of specification.

It is important to have the traditional methodologies such as APQP and Quality Gates better focus on the supplier level, questioning about the parts maturation and monitoring its evolution at supplier, to alert the entire chain about risks during execution / completion of the project.

Later correction of the dimensional deviations in "real" parts requires enormous effort, resulting in countless "long" and "complex" interventions. Results obtained are not "so efficient" if they were addressed during tool design/project (tool prepared for "complex" / interventions / "safe steel").

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