Dourado, João Paulo
Silva, Rui
Silva, Ângela Maria Esteves da

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Resumo Reducing time-to-market is the main goal of most companies, to enter the market sooner, build market share and maximize return on their investments. The use of concurrent engineering, Advanced Product Quality Planning (APQP) and quality gates are important in the New Product Development (NPD) process, but it is important to focus in the points on where the tools are not flexible and reinforce the process. The main focus of this work reveals that concurrent tasks between customers and suppliers ...

DEVELOPMENT OF NEW PRODUCTS USING APQP AND QUALITY GATES

João Paulo Dourado
jpdourado@fam.ulusiada.pt

Rui Silva
rsilva@fam.ulusiada.pt

Ângela Silva
asilva@fam.ulusiada.pt

Centro Lusíada de Investigação e Desenvolvimento em Engenharia e Gestão Industrial
Universidade Lusíada de Vila Nova de Famalicão, Portugal
Largo Tinoco de Sousa, 4760-108 Vila Nova Famalicão

Abstract: Reducing time-to-market is the main goal of most companies, to enter the market sooner, build market share and maximize return on their investments. The use of concurrent engineering, Advanced Product Quality Planning (APQP) and quality gates are important in the New Product Development (NPD) process, but it is important to focus in the points on where the tools are not flexible and reinforce the process.

The main focus of this work reveals that concurrent tasks between customers and suppliers cause most of the delays in production and are the basis for further work. Methodologies and tools to reduce time-to-market are presented and discussed. Conclusions are drawn that suggest improvements regarding concurrent engineering approaches and their critical issues. Major bottlenecks are presented based on the revised literature.

Key-words: New product development; APQP, Quality gates.

1. INTRODUCTION

The development phase of product demands new solutions in order to present more elaborated products and, objectively, cheaper. For that, the products should be launched faster and faster and with quality adequate to the structure of lean manufacturing area. That means we must ensure the manufacturing of a product with the highest degree of maturity within the time agreed with the customer in order to assure its satisfaction. The degree of maturity represents as the status of the project that responds to all customer needs when they receive this and keep the quality level during the time of your use. It also refers to the high degree of product maturity, which, during the whole period of its manufacture, maintain the level of quality (according to the agreed specification and quantity), and only incorporate improvements through programs such as the "continuous improvement".

As a result, companies are using a new organizational structure for its processes of New Product Development - NPD - which, unlike the traditional form, is based on an integrated approach related to the Concurrent Engineering

(CE) where all involved working activities are executed in parallel and with all the required connections that are established between the activities of different departments. The objective is to avoid continuous setbacks and other problems that arise with the traditional "sequential stages" approach and, with this, improving NPD performance – by Concurrent Engineering. With CE, the organization tries to accelerate the process, increasing flexibility by adopting a more strategic approach with solving problems through teamwork, developing different skills, and improve internal communication.

CE refers to bringing design and production engineers early in the design phase and simultaneously develop the product and manufacturing process of the product. The basic concept of CE refers to take the process of product design out of the isolated world of design engineers and incorporate other functional requirement that has, or should have, an influence on the design. It is expected that the application of CE on the process NPD will lead to the development of a product better, easier and cheaper in less time.

2. CONCURRENT ENGINEERING

The definition of concurrent engineering (CE) was first introduced in 1988 by the Institute of Defense Analyze (IDA) and, since then, CE has been the choice of many companies to restructure their business processes with the implementation of integrated management system, which interventions takes into account the quality, career, health, safety and environment. CE is commonly considered as a systematic approach to integrate the design of products and their related processes simultaneously, including manufacturing and support processes. As a philosophy of engineering and management, which also deals with the issues of the life cycle of a product, the most striking feature of CE is multidisciplinary, cross-functional team approach (Shouke et al., 2010). As a direct result, the tangible improvement in quality, cost, time, etc. has been achieved by those companies who applied CE. In some applications CE report 30-60% reductions in time to market, 15-50% of the lifecycle costs and 55-95% in engineering change orders (Fine et al., 2005).

Since its implementation, CE has been proposed as a method to deal with the problems that tend to arise when companies adopt the traditional approach of "new product development" (Valle and Vazquez-Bustelo, 2009). With this approach the development of a product follows a process structured in sequential stages which are clearly defined, such as; the "future" product is defined, projected, transferred to the plant and passed to the market. Each of these activities begins only when the previous one has finished completely, resulting in a total lack of integration and coordination between the different functional areas and other groups of employees involved in the process inside the organization. Each element carries out its work in isolation, with minimal reference to the needs of others. By this, many quality problems arise, primarily

due to lack of communication and understanding between product design, production and customer needs.

To achieve the above objectives, CE is based on three basic elements: (1) workflow which operates simultaneously, (2) the "in time" involvement of all participants and groups that contribute to product development, and (3) of teamwork (Valle and Vazquez-Bustelo, 2009). CE is the involvement of a multifunctional team, to simultaneously planning activities of product, process and manufacturing.

3. NEW PRODUCT DEVELOPMENT – NPD

The basic premise for the development of new products (NPD) in the context of concurrent engineering is that all elements of the life cycle of a product - functionality, manufacturability, assembly, validation, maintenance, environmental impact, and finally elimination and recycling should be taken into careful consideration in the early stages of the project.

Unlike sequential development, this first basic element refers to having parallel work-in-flow activities that are part of the process of NPD (Valle and Vazquez-Bustelo, 2009), stimulating the development of all parts of the project. For example, product design and planning process can be performed simultaneously. Planning process can be integrated with production planning and control or product planning can begin long before the concept is finalized. This does not reduce the duration of each activity, but can reduce the overall development time. In addition, working in parallel allows exchanges of information between the parties, so that the activities that traditionally occur much later in the process of product development, to benefit from information generated in large part from earlier activities, thus minimizing unplanned errors and corrective developments.

An NPD process (Kowang and Rasli, 2011) typically consists of five distinct phases:

1st Phase: Opportunity identification (the identification of opportunities),
2nd Phase: Concept development (development of the concept or idea),
3rd Phase: Product design,
4th Phase: Process design (testing process, or validation) and
5th Phase: Product commercialization / launching (release or marketing of products).

Opportunity is a gap in business or technology that a company/organization discovers that exists between the current situation and an imagined future, in order to respond to a threat, to solve a problem and/or to capture a competitive advantage. The identifications of opportunities can be achieved through market research.

At the stage of concept development, the opportunity identified is transformed into an initial product concept, followed by the detailing of the

product design, the development process, the product design and the design phases of the process. The newly developed product must pass a series of tests before the release of the product during marketing.

Each NPD phase has objectives (especially fulfillment dates) that are followed-up in order to achieve a successful project.

Other authors increase the number of stages of the NPD in order to detail more the activities and the scope of each one. For instance, Robert G. Cooper (1983) presented a model for new products development more specific and detailed, but with practical and direct use, considering 7 stages of decision: idea, preliminary evaluation, concept, development, tests, pilot production and launching (Garcez et al., 2007).

4. ADVANCED PRODUCT QUALITY PLANNING - APQP

Advanced Product Quality Planning is one of the tools of the quality management system required by the norm ISO/TS 16949 used in the automotive industries. The methodology considers five steps: planning, conception of the management system, definition of the control methods, and approval of the management system, critical analysis and improvements. The application of this methodology allows the identification, the analysis and the risk control. Nowadays the APQP is an obligatory requirement for the delivery of products to the companies inside the automotive chain, since it works as a guide in the development process and, also, a standard for result analysis between suppliers and organization (Benincá and Sellitto, 2010).

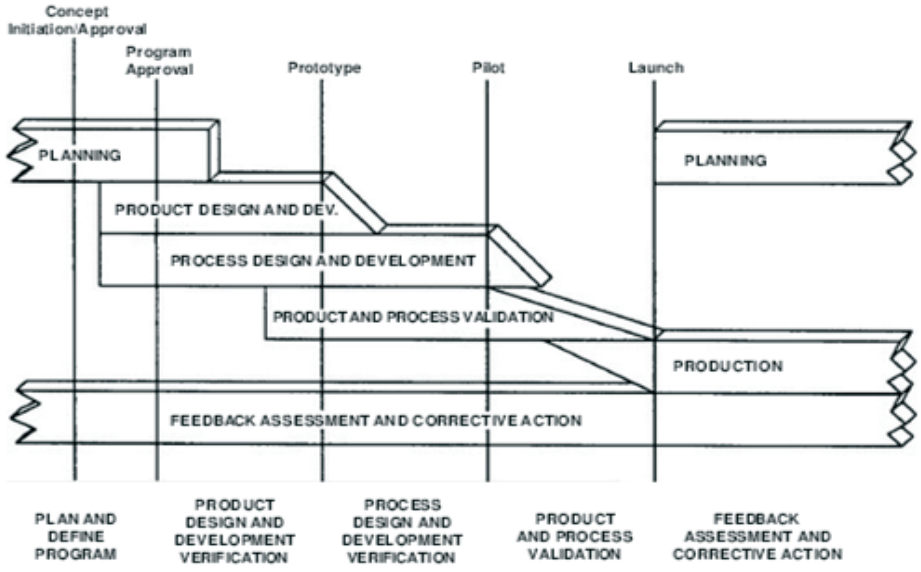

Figure 1: Product Quality Planning Timing Chart (Source: Shouman, M., 1994)

The APQP process is defined by the APQP manual from AIAG, Automotive Industry Action Group, a nonprofit 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 required changes in product and process and product development on schedule, with lower cost and with attention to customer requirements.

The first step in planning the product quality to the automotive industry is to choose a responsible for the APQP project, and this should be appointed by top management.

A cross-functional team should consist of representatives from production, engineering, quality, receiving materials, human resources, health and safety, security of assets, sales, purchases, post-sales assistance, also the suppliers and customer, if appropriate.

A cross-functional team of APQP, in the initial stage of the program, should meet to define: (a) the roles and responsibilities of each represented process; (b) a schedule for the five stages of the APQP process; (c) the costs that must be considered.

It is recommended that the APQP team should consider the application of the "concurrent engineering" to accelerate project, the activities should be carried out simultaneously, to avoid unnecessary delays.

During project implementation, the team will face problems. It is the responsibility of the APQP team establishes a disciplined approach to problem solving – for example: benchmarks, PDCA (Plan, Do, Check, Act), cause and effect diagram, flowchart processes, FMEA (Failure Mode and Effects Analysis) and record the problems. The success of the team depends on commitment and support of the organization's direction.

5. QUALITY GATES

Quality Gates were initially applied to product development processes especially quality control in the automotive industry. Since then, Quality Gates have been more broadly applied to quality assurance and project management and has been successfully applied as a quality assurance mechanism in several industries. (Ambartsoumian et al., 2011).

The concept of Quality Gates is based on the stage-gate system initially presented in 1986 and later optimized by other researchers. It consists on breaking down a project (or process) into several distinct phases. Then, quality checkpoints (or gates) are placed between phases to check the degree of fulfillment of a project or the quality of "in-process" artifact that is being manufacture (product).

In general, a Quality Gate marks the formal end to a particular process within a project, a "gate" through which the project proceeds from one phase to another.

Each gate results in the certification that all appropriate work required

to move products forward to subsequent project activities has been completed and reviewed and products meet specific quality expectations. Resuming, the procedure Quality Gate results in a pass / fail decision for moving forward, based on a set of pre-determined exit criteria established for each phase or milestone that is being checked. However, Quality Gates criteria can also include the success of other Quality Gates in such a way that Quality Gates can be interconnected with each other.

Quality Gates can also serve as a point of synchronization of process results and entry and exit criteria must be met before the product is able to continue throughout the process. Quality Gates help to break down the overall requirements on the final process result into sub-targets for the single process steps and to clarify the internal dependencies of the process chain.

Additionally, Quality Gates need not run only serially, but can (and often) run in parallel. That is, different sub-processes run independently but at some point filter together as products outputted from one phase are used as inputs for the next phase.

A major task for organizations that implement Quality Gates is determining where during the production process they should be implemented, how to structure and define Quality Gate criteria and how Quality Gates relate to each other.

6. THE SUPPLY CHAIN – SUPPLIER PERSPECTIVE

As referred initially, all the previous mentioned tools, especially the concurrent engineering are related to product life cycle, from conception to disposal, not only between company and customer but also with the suppliers nominated for the purchased parts. Purchased parts are not only single parts but also sub-assemblies, which are not planned for its execution inside the company, done outside the organization by external companies (Dourado et al., 2011).

At first sight, the goal is to obtain parts according to specification in quantity enough and delivered in time to attend the orders of product manufacturing of the organization. To assure this, it is necessary to confirm the feasibility of supplier manufacturing process: Parts are stable in terms of manufacturing and, also, dimension.

A robust design helps to get this desired dimensional/appearance stability in manufacturing process of the supplier.

The next is to implement lean production. To do this, it is necessary to consider the "Value Stream Mapping" and "Scaling" of the whole project - supplier -> company -> supplier chain - in order to implement the just-in-time strategy. Considering a "lean philosophy", aspects like supplier location, agreement referring to purchased parts package (one way or returnable package) are important. Continuing on the "lean philosophy" we can orientate the integration of individual parts, generating "sub-assemblies" to be delivered by the suppliers making easier the manufacturing process inside the company.

The project at the supplier runs concurrently with the project inside the company / organization. Both time schedules are connected with the items referring to parts delivery (even sampling). Any delay caused by one of the suppliers will cause a delay in time schedule of the final product from the organization. In the same way, any delay caused by the organization, such as, a late design change, will cause a delay in supplier time schedule resulting on a delay in time schedule of the final product (chain reaction). The acceptance by the supplier of a design change during this phase shall be properly evaluated, not only in terms of technical/costs situations, but also, referring to deadlines agreed with the organization. Probably some of the design changes required can be considered as running after Start Of Production (SOP).

All projects have planned a certain number of qualification series using purchased parts in different maturation stages (of the manufacturing process and / or different design / concept level). Sampling shall be agreed with the company in order to have parts delivered by supplier in proper time. Products, as purchased parts, are in different mature levels when attending the period of time considered in the time schedule. The products once assembled are submitted for qualification, conformity and functional tests. The results are evaluated requiring actions to be implemented together with the supplier or resulting in alterations of design.

Initially, the goal is to achieve the design freeze in terms of concept in which the final customer is satisfied with the product achieved. Achieving that, the goal changes to finalization of the parts approval process in which the supplier should present evidences of dimensional capability and total feasibility.

7. WEAK POINTS OF THE PROCESS

Although the organizations, especially the automotive ones, have a severe process for the validation of the product before to be submitted to the final customer for final release, sometimes all these stages of the validation process is not enough to cover all possible failures and, besides that, the organization itself, does not have internal mechanism to improve the whole systematic based on findings of problems solving techniques applied on previous projects on the scope of "lessons learnt" and "continuous improvement process" (CIP) philosophies.

One typical example is how the requirements / specifications of a final product are deployed to the sub-assemblies and individual components; of how a component (purchased part) is approved in terms of dimensional verification, capabilities evidences, measurement matching, quantities confirmation and engineering tests (from the organization or the final customer). The question is the following: have all possible evaluations/analysis – objective / subjective - considered in the specifications of the component and subsequent assembly to prevent any failure in serial production?

It is important to focus if the importance is over the fulfillment of the "paper work" or the "component" itself – in terms of appearance / functionality / use.

In case of quality claims which analysis of the root cause is beyond the fulfillment or not of any / all engineering requirement, the organization takes in consideration more complex and expensive evaluations – for example: laboratorial analysis - with support of organizations / external experts in order to find the root cause, especially for the claims which jeopardize the quantities and quality of the parts to be delivered.

The process cannot stop / finish when the root cause is found and the corrective actions applied inside the suppliers (in case of purchased parts) or the organization (manufacturing area) for the occurrence moment. Thinking only preventing reoccurrence for the running project by choosing a different raw material or improving a manufacturing process is also insufficient. The additional / extra activities performed should be integrated in component / product specifications for the first validations in the following projects. Of course this brings additional costs for the project which is against any business negotiation, but the costs would be smaller when happens in the early phase of the project with time for reaction in comparison of happening when the product started serial production – quantities / quality are in risk for the final customer.

The other concern for the organization is to be able to provide solutions / alternatives for the problems that can affect the logistic chain when the serial production, such as:

(a) Choose specific raw material with "long" "lead-time" / "delivery time".
(b) Choose raw material with "pot-life" / "lifetime" too short.
(c) Organization specified a "general purpose" raw material, then, raw material suppliers decide to finish with its production.
(d) The product design is supported by tests done inside the organization using an available batch of raw materials, but not considering / testing the manufacturing tolerance of the same material to confirm feasibility of the results / specification.
(e) Due to the organization have specified a very complex purchased part at external supplier and the investments made by the organization in those suppliers to have the components "tailored" are unique for the project without any alternative. Any problems detected implies in an immediate cut of supply without any possibility of alternative.
(f) Dimensional requirements out of specification – affecting (or not) the parts / final product functionality:
  - There is no "matching" of measurement method done at the organization and suppliers. Both methods are different. Which is the correct one?
  - Dimensions near the tolerance border without capability evidence.
  - Deviations accepted during PPAP approval but not recorded in the organization drawings / documentation (without updating the documentation from organization engineering).
(g) There are not established acceptance criteria for the external appearance of the purchased parts - especially when it refers to "appearance parts" with requirements for visual, such as color / brightness / surface finish (smooth / rough) /others.

Also it refers to "not existing / defined" criteria for visual defects, such as: spots; risks; other defects from manufacturing processes or from tooling wear-off (or outdated tool).

8. DISCUSSION

To know exactly where / which are the weak points of a Project is difficult, especially when the organizations are focused in being innovative in terms of novelty or in terms of new technology applied on the manufacturing process. Some of the organizations prefer to be simple in terms of experimentations / specifications / validations and, in this way being more agile and faster to launch new products on the markets in comparison with other "old fashioned" ones that have specification for everything and spend time on having a robust design.

In this, situations commented in the previous item appear easily. In matured organizations, when situation like that happens, they are recorded properly for new projects. Tools like "lessons learnt", and already discussed D-FMEA, P-FMEA are the preferable vehicles to assure that all points are considered / discussed in future projects.

Simulations of possible scenarios to evaluate the risks involved on the NPD project fulfillment or even considering a product already in mass production should be realized and the use of software like Petri Net can be useful.

The Petri Nets (PN) seems to be very attractive because they provide a suitable framework to represent the concurrent reasoning of active objects that share resources and their status changes. Due to its graphic nature and ease of validating specifications by analyzing the network structure, Petri nets are useful in providing simple and readable modeling to complex problems.

In view of complex nature of modern industrial systems, the design and operation of these systems require modeling and analysis in order to select the optimal design alternative, and operational policy (Armaneri, 2006).

Unfortunately these systems and techniques do not have well-defined syntax and semantic, which makes harder the complex analysis of models (de Pádua et al.,2004). Petri nets, as graphical and mathematical tools, provide a uniform environment for modeling, formal analysis, and design of discrete event systems (Armaneri, 2006).

In this case, Petri nets have excellent potential to solve the problem, once they present graphic representation and easy understanding (de Pádua et al.,2004). They are used as a communication language among expert people in different areas, and may allow the description of static and dynamic aspects of the systems that have to be represented. Also, they have mathematic formalism, which make possibly the use of the analysis methods.

One of the major advantages of using Petri net models is that the same model is used for the analysis of behavioral properties and performance evaluation, as well as for systematic construction of discrete-event simulators and controllers. Petri nets have been used extensively to model and analyze manufacturing

systems (Armaneri, 2006). In this area, Petri nets were used to represent; simple production lines with buffers, machine shops, automotive production systems, flexible manufacturing systems, automated assembly lines, resource-sharing systems, and just in time and kanban manufacturing systems

Petri nets are a powerful modeling formalism in computer science, system engineering and many other disciplines. The theoretic aspect of Petri nets allow precise modeling and analysis of system behavior, while the graphical representation of Petri nets enable visualization of the modeled system state changes.

Petri Nets are well suited for modeling complicated systems since they capture the precedence relations and interactions among events (Wu and O'Grady, 1999). In addition, a strong mathematical foundation exists for describing these nets, thus allowing a qualitative analysis of such system properties as deadlock, conflict, and boundedness.

9. CONCLUSION

As discussed, there are a few issues to be considered for improvement in the whole process of producing goods, since the effects of the incomplete specification, criteria for supplier nomination (based only the submitted quotation), validation of project of tools, consequent time schedule, consequent follow-up on the supplier, revision of the project (quality assessment gates) and others. As it was shown, in both companies and suppliers, most tasks run concurrently and problems a have tendency to merge between both, at some moment during project execution. Concurrent tasks between customers and suppliers cause most of the delays in production. Methodologies and tools should be the focus of further investigation in order to improve quality requirement issues in order to depict improvements regarding concurrent engineering.

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