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Product development methodology: non-quality caused in production by mistakes in product development, its measurement and improvement integration in the product development process

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Abstract: A new quality focused product development (NPD) methodology, applying lean manufacturing principles and Industry 4.0 paradigms is described in this paper. This methodology has been tested in a tailor-made equipment manufacturer for the retail sector, where tight product development times are needed. This requires a high agility in the processes, meaning the overlap of phases, the integration of processes, cooperation, and automation of tasks. We have generated a system concept that collects all the manufacturing incidences related to NPD, integrated in workshops stations, creating a system that enables real time data capture and a valuable feedback loop to NPD processes. Its implementation showed an improvement over 10% in the quality of the NPD process in a period of 3 months, an increase of the productivity in both product development and manufacturing areas, and a boost of the internal customer satisfaction in manufacturing area with the product development area.

Keywords: Case study, Methodology, Quality, KPI, Product development.

1. Introduction

New product development (NPD) along with the processes required for the generation of technical documentation are key among industrial organizations [1]. Traditionally, NPD has been considered responsibility of product development areas, who carry out all the required sub-processes for turning customer specifications into a new product and generate the necessary documents to make it manufacturable [2]. The time span of all these subprocesses differs widely among companies depending on many factors such as the sector, the company size or the type of product [3].

Additionally, product development has been traditionally considered as a very creative, manual and technical process, where new technologies or lean concepts were considered difficult to implement to improve NPD process' quality or productivity [4] [5].

It is not a modern area of concern, rather it has been an area of active research for decades. The new product development methodologies based on lean production principles or concurrent engineering makes one wonder whether the so called lean product development [6] is a new practice, a new method or an encapsulation of already existing methods [1].

Nevertheless, there is an increasing number of attempts to transfer Lean manufacturing principles, tools and techniques to other processes, such as NPD [8]. These practices are often designated as 'lean



product development', but they are highly under-investigated [7]. There are many differences between NPD and manufacturing processes, so Lean principles have to be modified to work successfully [5].

For industrial companies, a crucial nexus for achieving adaptability and minimizing lead time involves the joint work between NPD and manufacturing [2]. NPD processes based on Lean manufacturing principles (avoiding waste, kaizen, standardisation, visualization, flow and pull, zero-defects, leadership and frontloading [6]) combined and integrated with production processes for the common optimization, could be a new approach. There are scarce references found showing tested methodologies and case studies about implementing manufacturing total quality management concepts and criteria in NPD processes [9]. Thus, product performance is basically assessed in terms of three key criteria: quality, cost, and lead time [5].

Finally, we would like to point out that Industry 4.0 is a global term extremely used in the manufacturing area but much less known and used in Product Development phases. Normally, Industry 4.0 paradigms are linked to production or automation departments [10] and very little to creative activities such as NPD. In addition, the possibilities of application of Industry 4.0 paradigms in quality management are extremely wide [11]. Industry 4.0 is a data-driven paradigm because it makes better use of data to create more value. Although, there are many technologies to collect, transmit or condition data; value-creating technologies which apply data in order to develop new solutions are still rare in literature [12]. Industry 4.0 and quality models share the same objectives of improving quality, productivity and flexibility, yet their approach is completely different [13].

In this paper, we develop a new methodology for NPD that integrates production and quality processes as key players, applying lean manufacturing principles and Industry 4.0 paradigms. We have generated a system concept that collects all the manufacturing incidences related to NPD. Data are captured directly from the process and mined through analytical techniques to manage this real-time information and feed it back into the development process. This allows to analyse the problems' root causes and to develop solutions in a short and efficient way. The root cause analysis of all these incidences and its ranking reveals the guidelines to redefine the methodology, which is implemented through an iterative process.

2. Case study context

This research comes up in the context of a company dedicated to the design and manufacturing of equipment for retail, where over 10,000 new selling references per year are created. This organisation will be referred to as ABC throughout this paper due to non-disclosure requirements.

In this company, product variants are really numbered, and life cycles are extremely short. In addition, ABC employed in 2019 more than 150,000 hours of engineering for developing new products, which have an average lead time of 25 days in NPD process, and 15 days in production. Although, there are service KPI's, there is no measurement of the internal quality level of the NPD process.

In ABC, customer incidences in the market due to mistakes in NPD process are measured in terms of number of incidences and non-quality costs. However, there is no information about incidences in the manufacturing process caused by NPD process' mistakes or inefficiencies. Therefore, there is no measurement of the internal quality of the deliverables of the NPD process.

In general, quality issues caused by mistakes in the NPD process are solved instantly during manufacturing, when they affect the quality of the final product. But neither the root causes are analysed, nor there is an established learning process from these mistakes in order to avoid them in the future.

This situation is common in the most of the companies out of the automotive sector and it involves very high non-quality costs in terms of detection, false alarms, inspection costs, repair costs or costs of transferring defective units to the next processes, among others [14].

On the whole, not knowing the real cost of the NPD process mistakes, linked to organizations' fear to a measurement system over-bureaucratized and anti-productive for analysing these internal incidences, results in not investing in such a system and therefore losing potential improvements and knowledge of the internal quality of the NPD process [14]. Nevertheless, the cost of quality is of more strategic and economic importance than previously conceived.

3. Initial situation

The initial activity of the research was to analyse in detail how internal quality was integrated in the NPD process of ABC; and to measure and categorise the incidences caused by NPD process mistakes in manufacturing phase.

The NPD process flow in this paper starts with the entrance in Product Engineering Area of the request of a NPD and it finishes with the production delivery. Process' output refers to how this product is going to be aesthetically and constructively, and all the documentation and files required for manufacturing it: 3D and CAM files, manufacturing drawing, bill of materials, list of processes and production time of each process for the product and all its subcomponents, etc. Current NPD process can be mapped in nine sub processes as shown in figure 1. Sub-processes in white background are the ones with activities related to assure and improve the quality of NPD.

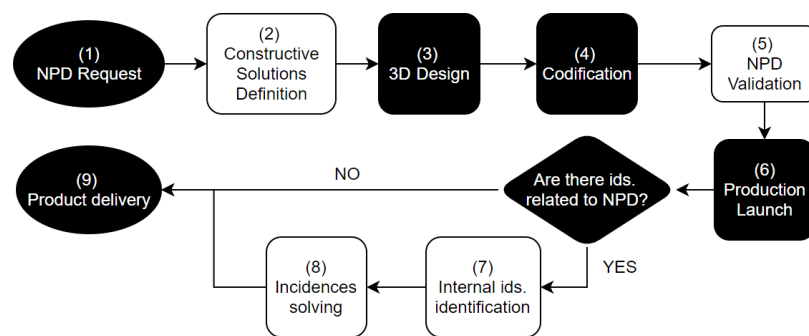


Figure 1. NPD Process initial situation.

- (1) Process starts with the entrance in the Product Engineering Area of the request of a NPD. It must be assured that all functional, quality, safety and aesthetical needs requested by the customer are fulfilled. All these needs are collected in a briefing document.
- (2) From the briefing, product responsible makes a detailed analysis to identify the best constructive solutions (including materials and process, for example) which solves the functional, quality, safety, and aesthetical needs of the request. For that, he/she uses his/her experience, the standardised constructive solutions, inquires to the technical experts or the workshop specialists, or uses the solutions of similar products. There is no standardised or formalized procedure, and the way these solutions are defined depends on the product responsible experience. This is the first sub process where activities to assure the quality of the output of the NPD process appear, as it must be analysed which are the best constructive solutions to fulfil all the requirements.
- (3) Once the constructive solutions are decided, the product responsible or a product engineer of his/her team creates a 3D of the product and its subcomponents with a CAD software package.
- (4) Once 3D is finished and, therefore, the product is fully defined, the assembly and all the new subcomponents are codified; bill of the materials and list of processes with the corresponding times are introduced in the ERP; and manufacturing drawings with dimensions, tolerances, critical dimensions, and welding indications are generated and inserted in the PDM.
- (5) After, product development is validated through the 3D, a mock-up or a prototype. This validation assures that the product developed fulfils customer specifications. However, it is detected that there are not clear guidelines about when one method or the other should be used. Validation method is chosen considering the time available for the project.
- (6) Once the product is defined, codified, and validated, production can be launched.
- (7) During first manufacturing series, incidences related to mistakes in NPD process arise. These are reported by phone or email to product responsible but no formal registration exists.
- (8) If an incidence stops production, actions to correct them are launched following the existing

procedures, as soon as possible. If not, it is registered in a file to implement actions if there is a second manufacturing. This is because 52% of the references developed in ABC are produced only once. Nevertheless, it is usual that in the second manufacturing batch, the same mistakes arise again because they have not been previously corrected.

(9) When manufacturing process is finished, the product is delivered and after sales process begins.

In this process, incidences due to mistakes in the NPD process are identified in the manufacturing phase, but there are no problems' root cause analysis, learning feedback to other products, or transversal improvements to make the NPD process more robust.

In this initial situation analysis, two different types of requests have been identified:

- NPDs which are variations or dimensional changes of previously developed products. In these cases, constructive solutions are defined from the technical solutions of similar products.
- NPDs where no similar previously developed product exists. In these cases, constructive solutions are defined inquiring technical experts or workshop specialists or using the previous experience and knowledge of the product responsible.

Besides, the general internal customer satisfaction of the manufacturing area with the quality of the product engineering area output was in general very low (1.3 in a scale of 5).

4. NPD Methodology with integrated quality phases

The NPD methodology proposed in this paper integrates production and quality processes and data, applying lean manufacturing principles and Industry 4.0 paradigms. Target is to measure and reduce the non-quality costs in manufacturing of the mistakes made in NPD process and, for that, data collection, data analysis and create feedback loop to NPD with this information is a key point in the methodology for improvement. This new methodology focuses on three main areas related to lean six sigma methodologies (PDCA: Plan-Do-Check-Act or DMAIC: Define-Measure-Analyze-Improve-Control):

- Data collection: all incidences generated by NPD process in manufacturing phase are registered. This is the base for future automatic data collection as a basis for Industry 4.0 application.
- Data analysis: root cause analysis of the registered incidences is implemented.
- Feedback to NPD process: taskforces to avoid or remove the most repetitive causes are created.

As a result, we defined four new sub processes in the NPD process to cover the three previously mentioned target areas: registering internal incidences of the NPD process in manufacturing phase, root cause analysis of the incidences of the NPD process in the manufacturing phase, launching root cause elimination taskforce for incidences of the NPD process in manufacturing phase, and follow-up and impact measurement of the defined actions (processes 10 to 13 grey shadowed in figure 2).

4.1. Sub process 10: Registering internal manufacturing incidences due to NPD.

In data collecting phase, direct phone call or email were replaced by a standardised process with a form filled online by the internal customer that is registered in a data base. This form is used to register all the incidences that arise during the manufacturing phase caused by mistakes in the NPD process.

4.2. Sub process 11: Root cause analysis of the incidences.

This process includes the analysis of the incidences (data), their categorisation and root cause analysis. The root cause analysis is executed through lean tools adapted to the NPD process, such as: 5 WHYS, Pareto's or Ishikawa's diagramm. In this process, problem must be clearly defined, potential causes must be identified and the incidence's cause is validated by reproducing it and its consequences.

A root cause is validated as root cause when it reproduces the identified problem and it allows to define actions to eliminate its occurrence or increase its detection.

4.3. Sub process 12: Launching of root cause elimination taskforces.

Root cause elimination taskforces focus on eliminating root causes through transversal improvement actions. Through these actions, the quality feedback is implemented as a loop into the product development process. In order to implement this process, it is required to have enough data to identify the root causes which cause the most of the incidences.

An Internal Quality Project Committee (IQPC), formed by the Product Engineering Manager and the Technical Experts, was created to foster this phase. They select the most repetitive root causes which need a taskforce. It holds a weekly meeting to follow-up new incidences and decide the new taskforces to launch. Taskforces are led by the technical experts and focused on the following type of actions:

- Training and consciousness of the teams.
- Definition and implementation of the new working standards or correction of the existing standards that did not work.
- Creation of poka-yokes in the NPD process to avoid incidences.
- Automation of NPD tasks to avoid incidences.

All these types of actions lead to an improvement in the NPD subprocesses. Additionally, IQPC analyses KPIs (number of incidences per category and ppm's, among others) in order to measure the impact of these improvements in the internal quality of the NPD process. Taskforces and KPIs are shared monthly in a meeting with manufacturing managers to evaluate their perception about the improvements.

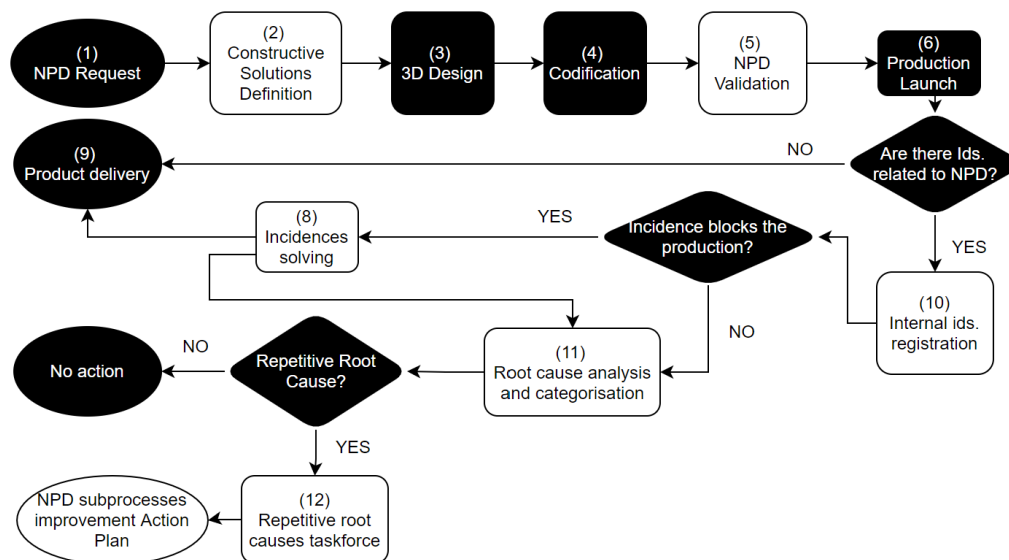


Figure 2. NPD with new quality management phases.

5. Pilot test in ABC

This new methodology was tested in ABC through a pilot test. Due to non-disclosure requirements, the description of this test will include generic denominations for categories and projects in tables of data.

5.1. Phase 1

Phase 1 lasted 3 months and included the implementation of the first two processes (incidences registration and root cause analysis) in one of the manufacturing areas, the metal workshop.

In phase 1, all incidences arisen during the manufacturing process due to mistakes in the NPD process were registered, categorised and analysed by the Metal Technical Expert together with the product responsible of each product. Categories in which incidences were classified were not pre-

defined. A summary of the incidences reported grouped by categories are shown in table 1.

The analysis of the incidences in this phase of the pilot test revealed that most of the root causes assigned to the incidences were: “I did not realized”, “There was not time to apply the defined procedure” or “I needed to launch the production and I did not have time to check the design”. These root causes did not allow to define actions to eliminate the occurrence or increase the detection.

Table 1. Incidences registered in phase 1 grouped by non-predefined categories.

METAL WORKSHOP	
CATEGORY	Nº of ID's
Mistake in CAM file	149
Mistake in manufacturing drawing	117
Mistake in constructive solution	84
Mistake in list of processes	35
Mistake in bill of materials	16
Procedure infringement	13
Mistake in process time	3
TOTAL	417

5.2. Phase 2

The conclusions obtained in Phase 1, resulted in three changes to implement in Phase 2:

- Categories standardisation: design, codification and product concept categories were settled, among others.
- All NPD process actors were trained in root cause analysis methodologies and tools.
- Root cause analysis were made by product responsables or product engineers and supervised by technical experts.

In Phase 2, incidences were registered and categorised with this system during 3 months. A summary of the incidences registered during this period, grouped by categories, is shown in table 2.

Table 2. Incidences of phase 2 grouped by categories (normalized to sales of phase 1).

Category	Subcategory	METAL WORKSHOP
Design mistake	3D mistake	4
	Mistake in CAM files	132
	Mistake in manufacturing drawing	124
Codification mistake	Subcomponent mistake	7
	Quantity mistake	14
	Phase mistake	18
Product concept mistake	Time estimation mistake	24
	Not appropriate constructive solution	46
	Not manufacturable	32
	Not functional	38
TOTAL		439

Root cause analysis carried out in this phase revealed a clear evolution on the failure cause definition.

5.3. Phase 3

Once root cause analysis allowed intervention, in Phase 3, the process of launching root cause

elimination taskforces led by the Technical Experts of the Product Engineering Area was implemented. A pilot taskforce worked on a very repetitive root cause of the metal workshop.

5.4. Phase 4

In phase 4, several taskforces were launched to eliminate additional root causes and the IQPC was implemented to follow the actions and measure their impact in the KPI's.

6. Results

The new NPD methodology was implemented in a real company with positive results. Table 3 shows the accumulated data for 3 months, normalised to sales of phase 1 (in order to make them comparable), after pilot taskforce actions were already finished. It can be observed a reduction of 12.5% in the normalised to phase 1 sales number of incidences.

Table 3. Comparison of data between data collection at the end of phase 2 (Old) and data collection after pilot taskforce actions were implemented (New) (normalized to sales of Phase 1).

CATEGORY	SUBCATEGORY	IDs METAL WORKSHOP		
		Old	New	Delta
Design mistake	3D mistake	4	27	+23
	Mistake in CAM files	132	97	-35
	Mistake in manufacturing drawing	124	108	-16
Codification mistake	Subcomponent mistake	7	9	+2
	Quantity mistake	14	38	+24
	Phase mistake	18	12	-6
	Time estimation mistake	24	27	+3
Product concept mistake	Not appropriate constructive solution	46	27	-19
	Not manufacturable	32	13	-19
	Not functional	38	26	-12
TOTAL		439	384	-55 (-12.5%)

Pilot test showed the following improvements on NPD process performance:

- The quality level of product engineering output for manufacturing area as internal customer has improved over 10%, taking into account that only a small amount of root causes were worked through taskforces. Main reduction took place in the categories where taskforces were launched.
- Product Engineering Area has taken consciousness of the internal PD problems that generate non-conformities in Manufacturing Area, thanks to the measurement and follow-up of the KPI's. This knowledge has reduced directly the number of incidences in some of the categories.
- Besides, internal customer satisfaction from the Manufacturing Area with the Product Engineering Area has also improved. Internal customer satisfaction has evolved from 1.3 over 5, before pilot test, to 2.8, after.
- Manufacturing area has increased the number of incidences reported in some typologies. In phases 1 and 2, only production blocking incidences were formerly reported but, once the taskforces were implemented and some root causes eliminated, the report of non-blocking incidences increased. These incidences were, before the new NPD process, easily solved by the workshop operators, but they caused a reduction in the productivity.
- It has also been detected an improvement in the training and knowledge of product responsables and product engineers without investing in external trainings. Root cause analysis make them realize about their weak points and boost their learning process and work quality improvement.

- Finally, actions defined in the taskforce process have evolved from introducing detection checks to elimination of the occurrence, whose impact is clearly more powerful.

7. Conclusions

This methodology is scalable and applicable to other companies with significant tailor-made SKUs per day in short timing. It also allows to monitor the development process through internal defectiveness indicators; generates significant learning and knowledge in product engineering areas; reduces wastes in the manufacturing phase; and creates continuous improvement in the global process. Besides, thanks to the process of taskforce for eliminating root causes, the proposed solutions become more creative and sustainable in time. Moreover, the implementation of Industry 4.0 paradigms in terms of collecting data and its application allows to make better use of them, and to create value by developing new solutions to avoid incidences.

All this is translated not only in a drastic reduction of internal and customer incidences, but also in a significant increase of the productivity in both manufacturing area and product engineering area.

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