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Advanced Product Quality Planning for Performance Evaluation of New Product Implementation Process: Application in a Factory

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Abstract: The variety of products in companies with order-based production system is high but the amount of production of each product variety is low. Therefore, each product is considered as a new product (NP) and challenges of not only producing NPs but also changing market and competitive conditions are faced. In order to overcome these difficulties and sustain the market share, it is necessary to produce high quality products at one time with minimum cost in all stages from the receipt of the order to the after-sales services in the production of NPs. In an attempt to solve this critical problem, our study focuses on the application of advanced product quality planning (APQP) technique, which is one of the most effective methods used in new product development (NPD) process control to ensure survival and continuous improvement of company and reduce the cost, time, labor and customer losses in the process of new product development. In this study, first, the NPD process and the use of APQP in NPD were explained and then an example of APQP application in a factory producing heat exchangers with order-based production system was given. APQP has been completed in three sections; process design and development, product and process validation, feedback and corrective actions. Process management and control activities and tools such as establishment of team, selection of NP, feasibility studies, determination of workflow, reduction of risks, determination of process capability and measurement systems analysis, creation of control plan, production, dimensional and performance tests were performed. As a result of this study, it has been proved that NPs produced by following an NPD process that is continuously evaluated with APQP method, fully meet both customer and company requirements. By using APQP method in NPD, process is controlled and scrap rates, costs and customer complaints are reduced.

Keywords: New product development, Advanced product quality planning, Order-based production system

Introduction

The order-based production system is a production model used to create a new service or product. It is a production system covering a small quantity but high level of product range. In addition to the similarity of the products to be produced at some points, a special effort is required in order to achieve innovation in the order-based production system. It is a production model that is mostly privatized according to customer and has the least standards. Nowadays, with the changing market and competition conditions, the companies realize customer specific production in order not to fall behind the market and not to decrease their market share.

In the order-based production systems, to put business rules and to measure and control the processes by making them a certain standard is difficult. Product variety and low production quantity reduce the repetition in processes to a minimum. Therefore, right production in one time is an extremely important criterion.

During the product development process that begins with the receipt of the order until the customer's use of the product, pre-determination of the failures and risks that may occur, taking the necessary measures, reducing of scraps, re-processing time, time and cost losses, customer losses and quality losses, offering the products to the market quickly are important requirements for companies to be ahead of their competitors. In line with these reasons, in today's conditions, application of the quality management by the companies which has this type

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production system provides excellent advantages to them. Quality management is defined as a fullest extent of planned and systematic activities applied to ensure sufficient confidence in the fulfillment of the requirements of a new product or service.

When the studies in the literature are examined, application of Advanced Product Quality Planning (APQP) technique in new product development (NPD) process in mass production system has generally been seen. In our country, enterprises that have project-based production system in global competition takes an important place. However, there are not sufficient studies in implementing APQP in NPD which minimizes the risk rates in this production system where the risk ratio, costs, customer satisfaction, quality, and product offer more rapid conditions. This study was inspired by the lack of appropriate solutions in the NPD process in companies that have a project-based production system. For companies that have such production systems, APQP technique, which is an effective method for NPD process management, has been proposed. APQP technique is thought to provide significant benefits for both literature and enterprises.

New Product Development

NPD means the research and development efforts that are revealed by the firms to develop original products, product changes or new brands that are required by the customer (Armstrong, Kotler, Saunders, & Wong, 2005). The new product may be something that has never been produced or changes in the existing product such as style, color, performance variations, dimensional differences etc. (Onal, 2009). NPD process includes strategic formulation, distribution, resource allocation and coordinated cooperation between people from different professions and nations, and many issues and challenges in a company such as systematic planning, monitoring and control. Therefore, the NPD activity is essentially a selection, transformation and coordination work (Loch & Kavadias, 2008). NPD process consists of three stages. These include; Pre-development activities, development phase activities, decision to production and market entry.

Performance Criteria in NPD Process

There are many factors to achieve success in developing a new product to a new market or to the existing market. Cooper (2000) collected the performance criteria in the NPD process in 10 different categories. These factors include; differentiated and superior products, preliminary studies - homework, listening to the customer's voice, clear, stable and early product definition, market research, go / kill decision points for the project, cross-functional project teams, determination of strong points and using them is the creation of a market and the support of top management (Cooper, 2000). Ernst (2002) based on the literature studies on NPD, divided critical success factors into 5 categories, namely, NPD process, organizational structure, firm culture, senior management role and commitment and strategy. Desai, Mital, and Subramanian (2008), based on Cooper and Montoya-Weiss and Calantone studies, identified NPD performance criteria under the headings of uniqueness, customer orientation and adaptation to the market, preliminary studies, clear and early product promotion, the execution of activities, organizational structure, project selection decisions, marketing, the role of senior management, speed without compromising on quality, systematic finding of new product process, market attractiveness, experience and foundation competences.

Advanced Product Quality Planning (APQP) in NPD

APQP defines the activities that determine customer needs and develops products and processes to meet these needs. In short, product quality planning is a structured method for identifying and realizing the steps in all processes such as production and marketing, where a new product idea is designed, researched, and designed to ensure customer satisfaction (Sanongpong, 2009). In APQP, directing resources to appropriate activities, determining the changes in advance, avoiding late changes, providing a quality product on time and at low cost are the biggest benefits (Khanna, 2005). APQP is used in new product manufacturing process and product or process change.

APQP Process

The success of a project depends on meeting customer needs and expectations on time. Product Quality Planning provides failure prevention works with time diagram. If the problem solving methodology is not sufficiently comprehensive, the solution will not be correct and the problem will reappear sooner or later. As shown in Figure 1, problems with an activity schedule will be prevented from occurring with Concurrent Engineering studies. The Product Quality Planning Team is responsible for ensuring that the timings are appropriate or earlier than the customer schedule (Kaushik, Khanduja, & Mittal, 2012; Book, Fick, Hopkins, Minkler, & Williams, 2008).

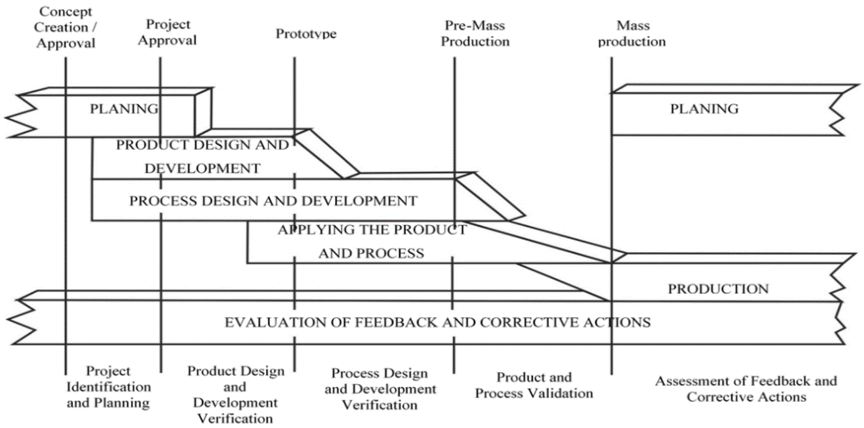

Figure 1 Advanced product quality planning time diagram (Book et al., 2008, s.5)

As shown in Figure 1, the APQP process consists of a total of five main stages. These stages are; project identification and planning, product design and development, process design and development, product and process validation, evaluation of feedback and corrective actions.

While suppliers with design responsibility have to implement all processes, suppliers with production responsibility are only required to apply process design and development, product and process validation, evaluation of feedback and corrective actions.

Problem Definition and Methodology

In this study, the name of the application company is kept anonymous for privacy purposes and is referred to as the ABC company. ABC Company has order-based production system where each order is in the scope of the new product. Approximately 15% of the production amount is reproduction in terms of product types produced on annual basis. The remaining 85% production is evaluated within the scope of new product. Many factors, such as product type, dimensional characteristics of the product, material type, product circuit, direction and notation are differentiated the order. For this reason, material properties and production methods are varied for each product which is differentiating. There are exponentially increasing risks in the process of delivering the product on time, in quality and in desired quantity to the customer due to changing conditions. Such risks lead to increased scrap rates, time and cost losses and, most importantly, prestige and consequently customer losses. Along with to order a different product is very difficult and also the number of products ordered is very low. For this reason, making accurate production is required at one time. Under all these circumstances, new product manufacturing and process management at ABC are considerably complex and difficult. Along with the challenges of having an order-based production system, in order to survive in a competitive environment, the company must offer products to the market quickly, in addition to products that fulfill customer requests and does not compromise on quality. Since the deadline of raw material is 6 weeks but deadline of product is 2 weeks, NPD process was more difficult. By managing all these challenges in the NPD systematically, producing on the right amount and on correct quality products at the first time is an important constraint for the company. The works to be done for it will put the company ahead of its competitors and increase its profit margin.

In this study, considering the difficulties in ABC Company has to deal with, a systematic process and product management approach based on key performance indicators will be developed for more effective and quality management of the NPD process. Within the scope of the research, APQP process will be applied for quality planning to avoid potential failures which might occur, which is aimed at continuous improvement and meeting specific customer requests in the production of new type heat exchanger. With efficient using of APQP in NPD process, will increase the success rate of the company and enable to meet the demands and expectations of the customers, increase the speed to market according to the competitors and achieve a competitive advantage.

Application

APQP methodology will be applied for NPD process in ABC company.

Section 1 and 2: Project Identification and Planning and Product Design and Development: Since the product design belongs to the customer, all necessary information has been provided by the customer.

Introduction of the Product that is Subject to Study: The product was an evaporator which is the main component of the vehicle air conditioner system that will minimize the heat transfer of the part allocated to carry the perishable product. The frame sheet, pipes, honeycombs and auxiliary parts of the product were designed as aluminum.

Feasibility Studies: The feasibility studies and whether the product can be made without order approval were evaluated by all relevant departments in terms of time, money, raw material and labor. The product can be made under the conditions of ABC company and the packaging conditions were in the standards that ABC can provide. Product raw materials were evaluated and stock controls were provided. Some changes have been requested on the customer's technical drawing in order to use the product effectively and to avoid nonconformities. It was communicated to the customer by the sales and marketing department and customer approval was obtained. According to the meeting resolution, Sales and Marketing Manager was selected as the leader for this project.

Section 3: Process Design and Development: In this section, production workflow, product material list, process failure mode effects analysis (PFMEA), measurement statistical analysis (MSA), Statistical Process Control (SPC), Control Plan and Packaging standards studies were performed.

New Product Production Flow Diagram: New product production flow diagram was same as standard production line

Material List for New Product: According to the product drawing, the materials to be used to produce the product, raw material list, usage amounts were determined on the basis of quantity and kg.

Process failure mode effects analysis (PFMEA): In order to determine risks in advance and to take precautions, the following PFMEA application steps were performed: Determination of Scope, Formation of the Team, Examination of the Process, Determining Possible Failure Types, Determining Possible Causes of Failure, Determination of Possible Failure Effects, Identification of Existing Controls, Determination of Severity, Occurrence, Detection Values, Calculation of R.P.N Value according to Equation 1, Evaluation of R.P.N. value according to Table 1, Determination and Implementation of Measures to be Taken, Calculation of the new R.P.N. value.

$$\text{RPN} = \text{Precaution (P)} \times \text{Frequency of occurrence (F)} \times \text{Determination (D)} \qquad \text{Eq (1)}$$

Tablo 1 R.P.N. Evaluation (Duru, Koç, & Taş, 2011, p.62)

R.P.N Points	**Activities**
R.P.N <= 40	There is no need to take precautions.
40 < R.P.N <= 100	It is useful to take precautions.
R.P.N > 100	Precautions must be taken.

According to PFMEA analysis, the R.P.N value of the four failure modes were greater than 100 and measures have been taken for these failure modes. The first of these four critical failure modes were the failure of the collector axis measurement and the second of them was failure of the distributor axis measurement. For these failure modes; special fixing fixture was made to prevent dimensional failure for fixing during brazing process. In addition, part support sheet was made to prevent dimensional deformation that may occur due to transport for the purpose of fix the collector and distributor to the mirror sheet. The third failure mode was improper brazing operation. To prevent this failure from occurring; brazing operator was trained and brazing wire with borax was introduced. The fourth failure mode detected was deformation of the mirror sheets due to brazing heat. To prevent this failure from occurring; a cooling pool was developed in order to made of the brazing process by cooling. As a result of the improvements, the new R.P.N values of all failure modes have been reduced to below 100.

Measurement statistical analysis (MSA): Method of measurement analysis was used to determine the adequacy of measurement systems. MSA Steps involved; determining the critical part and critical characteristics, to make the necessary settings to the instrument, selection of parts, numbering of parts, selection of operators, informing operators about measurement, 3 repetition of measurements, calculation of ranges, range average, UCLR value, the average of the operators and part, difference between the largest and smallest average, Repeatability - equipment variance (EV), The reproducibility - Appraiser variance (AV) value, Repeatability and reproducibility (GRR) value, The part variance (PV) value, the total variance (TV) value, The percentages of EV, AV, PV, and GRR in the TV, % GRR Evaluation, calculation and evaluation of number of distinct categories (ndc) value.

According to MSA, the GRR value was calculated as 12.88%. The value was acceptable because it was between 10% and 30%. The APQP team decided not to make improvements based on the accuracy of the part. The ndc value was calculated to be 10.888 as a result of the analysis. Since the value was over 5, the part category value was acceptable.

Statistical process control (SPC): This method was used to determine process variation after measurement variation was determined by MSA. SPC is a method used to monitor the process for detecting abnormal behavior in a process that is caused by specific reasons that are unnatural, unpredictable, and unregulated for the process, consisting of an uncertain source. (Baldan et al., 2018). Steps to apply SPC involved; determination of part and part number, the feature to be checked, the upper tolerance limits (UTL) and lower tolerance limits (LTL) of the feature to be checked, control frequency and sample size, measuring tool, machine, the date, shift, day and time of the measurement, making measurements, calculation of mean and range values, Calculation of Upper Control Limit (UCLX), Lower Control Limit (LCLX) for average and Upper Control Limit (UCLr), Lower Control Limit (LCLr) for ragne, drawing and evaluating graphs, calculation of standard deviation, calculation of process capability values (cp,cpk).

According to all basic control situations; measurements were within the control limits. The number of measurements between the centerline and UTL and the number of measurements between the centerline and ATL were similar. All measurement results were distributed randomly within the control limits. According to the calculated Cp = 1.96532317 and Cpk = 1.949601, the process capability was appropriate. Although the process meets the desired conditions, there would be unsuitable parts in the process outputs. However, the probability of detection was quite high.

Control Plan: The control plan includes all the controls planned to be carried out in accordance with the production workflow, customer, manufacturer, legal conditions and regulations. Steps to creating control plan involved; determination of scope, setting the team, examination of process will be applied, preparation of control plan. In accordance with the prototype production, all processes with their numbers, process characteristics in accordance with the product drawing, products subject to the process, all control methods, measurement method, frequency, sample size, registration forms and actions to be taken in case of inappropriate product were specified in the control plan. The approved control plan was informed in detail to the relevant process owners and production and quality control personnel. If necessary, instructions regarding the controls were prepared and trainings were given.

Packaging Standards: Product packaging standards were realized in accordance with customer packaging conditions, ABC company packaging conditions and legal regulations. Packaging standards were prepared as instructed and forwarded to the packaging and final quality control department.

At the end of each study, all data, documents, analyzes, findings and preventive studies were presented to the APQP team by the study leaders. As a result of the studies, all risks that may cause loss of time, money and firm prestige in product production were eliminated.

Section 4: Product and Process Validation: At this stage, production was carried out in accordance with the product technical drawing and control plan, bubble test was performed in the pool under 35 bar pressure with dry air for 2.5 minutes and dimensional measurements were performed for performance test. The product was packaged according to the specified packaging standards. All stages of pre-shipment packaging were photographed for customer approval. A Part Submission Warrant form was prepared for customer approval and sent to the customer with all documents.

Section 5: Feedback and Corrective Actions: The product has been checked by the customer and the product has received customer approval. No corrective action was requested for the product. On the customer side, the product was included in the approved product list in the approved supplier category.

Application Evaluation and Results

In the ABC company, which has an order-based production system, APQP technique was applied for evaluating the performance of the new aluminum evaporator product impentation process, all stages were carried out effectively and the results were analyzed. APQP team applied PFMEA as the first analysis after determining the feasibility, production flow diagram and material list. As a result of the analysis, 72 potential failure modes were determined. R.P.N. value of 17 potential failures were below 40, the R.P.N. value of 51 of them were between 40 to 100, The R.P.N. value of four of them was found to be over 100. Failure modes with a value of R.P.N. over 100 were focused on and preventive actions were initiated. With preventive actions, the R.P.N value of four critical failure modes was reduced to less than 100. As a second analysis, MSA was applied. Flare Sleeve semi-finished products to be used in new aluminum evaporator product have been selected for MSA. 10 samples taken from the production were randomly measured by three different quality personnel with three replications. According to the MSA, the GRR value was found to be 12.88%. Since the measurement system was between 10% and 30%, it is determined that the measurement systems are acceptable. In addition, the ndc value was found to be 10.858. Since the ndc value is greater than 5, it has been found that the measuring equipment has sufficient distinguishing feature. As the third analysis, SPC was applied to determine process adequacy levels. For SPC, flare aluminum union semi-finished products to be used new aluminum evaporator product were selected. Five semi-finished products were selected. Five sets were taken at different times provided that there were Five samples in each set. As a result of SPC application on a total of 25 samples, all measurement results were in the range of part tolerance. For the measurement range, UCLr was calculated as 0.50 and LCLr was calculated as 0. The calculated range values for all sets remained within the limits range and Cp and Cpk values were calculated to measure process capability. Cp value was calculated as 1.96 cpk values was calculated as 1.94. According to the common conditions of the customer and ABC company, Cpk value was required to be above 1.67 to indicate that the process was carried out under sufficient conditions. After eliminating the risks for the production of new products and determining that the measurement systems and processes were sufficient, a control plan was prepared in which all the processes that would enable the possible failures to be minimized were included. Information training was organized for all departments related to the control plan and necessary documentation was provided. Dimensional measurement and leakage test was performed on the product which was produced according to the determined work flow and provided accuracy according to the control plan. Dimensional measurements were within tolerances. According to the leakage test, it was confirmed that there was no brazing leakage on the new product. All these analyzes, dimensional measurements and performance tests were documented and presented to the customer with the product. The product has been approved based on the customer's documentation review and product controls.

Discussion and Conclusions

The APQP technique in NPD provides benefits such as ensuring product quality in new product production, reduction in delivery speed, customer satisfaction, lowering costs, and controlling processes. This technique ensures the systematic management of the processes by sustaining the participation of all employees with the continuous improvement of all activities in this technical organization. The APQP technique, which ensures that product realization activities are carried out under controlled conditions, was proposed and applied in ABC company which has an order-based production system where 85% of the product variety is evaluated as a new product and where the competitive conditions are the most difficult, and has a costly product and production line such as a heat exchanger. All activities to implement the APQP model in the production of new products in the company where the research is conducted were planned. APQP team was determined and new product to be applied was selected among the demands from the customer. The application was completed in five main sections. The first two parts of APQP are related with product design. Since the company has not design responsibility and it belongs to the manufacturer, the documents of the first two sections have been provided by the customer. Three main sections of the other APQP application were realized in the company. These sections are Process Design and Development, Product and process validation, Feedback and corrective actions. Inter-departmental critical meetings were held with the APQP team. Evaluations were made about the studies and the progress of the process. First, feasibility studies were conducted and the feasibility of the company was investigated. Product workflow was determined. The sections were completed according to the determined product flow. Some statistical techniques were used in practice. These are PFMEA, SPC, Process capability analysis, MSA. Using these statistical techniques, TV was measured, capabiilities were evaluated and risks were reduced. Then, production was made according to work flow. The whole process was controlled according to the determined control plan. Dimensional measurements control and performance tests have been performed on the completed product and it has been proved that it meets customer requirements and company requirements. The product, which has been approved, has been sent to the customer with all documents in accordance with the packaging and transportation conditions determined by the joint decision of the company and the customer. Thanks to the communication established between the customer and the company in the whole process from the order to the delivery of the product to the customer, many studies became easy to understand and unnecessary time losses were prevented. The customer has reviewed and approved the new product and documents. The APQP model was approved as an evaluation model for new product performance by the top management due to the advantages of APQP technique such as ensuring the right production of the product at one time and thus reducing the labor, time, cost and scrap rates, detecting and eliminating the failures at the source before supplying them to the customer, ensuring customer satisfaction, preparing the control plan for the product. Since 85% of the production is a new product, APQP technique has been used in the production of all products. In this way, the company has achieved a significant advantage over its competitors in terms of both price and quick return to the customer. As a result, it is aimed to increase the current market rate of the enterprise and to enter new markets.

In the production of new products, the APQP model is frequently used by companies in the automotive and aerospace sectors, which have a mass production system. Unlike these sectors and production systems, our work was carried out in the air conditioning and refrigeration sector and a company that has an order-based production system. The results of our study show that, the companies applying the APQP model in the NPD process, which have an order-based production system and which have high product and production costs, will have gains such as reduced product cycle times, increased productivity, reduced costs, increased customer satisfaction. In addition, increasing the quality of the final product, providing competitive advantage, increasing the existing market share, increasing the opportunities to enter new markets are among the other advantages. As a result, companies that follow a systematic approach such as APQP to evaluate and control their new product implementation process can ensure continuous improvement of company and reduce the cost, time, labor and customer losses in the process and hence increase their profitability rates.

As a result of this study, the APQP model, which is thought to be beneficial for the new product implementation processes in the automotive and aerospace sectors with only mass production systems, has been proven to be beneficial for the air-conditioning and cooling sector with order-based production systems. In future studies, APQP model can be developed for enterprises with production systems other than mass production and order-based production systems. Academic studies can be conducted on generic APQP models for enterprises with order-based production systems. Similar studies can be conducted in sectors other than air conditioning and refrigeration, automotive, automotive sub-industry.

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