

## DESIGN OF EXPERIMENTS: ITS IMPORTANCE IN THE EFFICIENT PROJECT MANAGEMENT.

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### Abstract

Organization success depends on the ability to determine consumers' needs and transform it into products of quality, produced in short time and low cost. Large time is spent in products design on conduction of experiments. A way to reduce design time is with an efficient conduction of experiments. Design of Experiments - DoE is a method that allows studying effects on process outputs with controlled variation of input variables. With the results it is possible to perform an analysis that allows to characterize and optimize the process, which led to data that permit decisions that lead to a better control of process and optimization of effects on product. The paper has as purpose to discuss how the use of DoE contributes to Project Management to reduce development time of products besides improving quality in all stages of product life cycle. Findings were that the use of the method DoE has great relevance to Project Management, since it provides a structured method for conducting experiments in order to provide data to allow decision making based on facts that lead to more competitive products in terms of quality, production time and cost.

### Keywords:

Project, Design, Project Management, Design of Experiments, Quality, Process Optimization.

### INTRODUCTION

The economic success of the organizations depends, principally, on the ability to determine the needs and wishes of the consumers and, to transform such needs in products of quality and/or services that can be produced in a desired schedule and with acceptable costs for the clients. So, the development of products and services has an important role in the success of the organizations in the market where they act; it can even determine if they will survive, or not, in the market. This market, each time more competitive, asks for products with shorter life cycle, and consequently, the costs invested in the development of new products and/or services need to be amortized in smaller periods.

According to Page [1], based on data about the medium life cycle of different stages of a process of development of new products or processes, it was seen that the physical development of a product is responsible for the biggest part of the product life cycle. So, can be perceived the importance that the process of physical development of new products and processes to manufacture it must be the most efficient possible.

Considering that it is recognized as a big part of the time used in the development of products and/or processes is used in the preliminary experiments, a way of reducing the time of product and process development is to lead the experiments more efficiently. But, it must pay attention to the fact that the experiments, when well conducted, lead to products with more quality and process of production with reduced manufacturing costs and with a shorter cycle of the development of products and processes [1].

Even with the existence of extensive literature about the Statistical Project of Experiments, it must be considered that this literature focuses, mainly, in the methods and technical aspects of the tools that are used in the methods.

In that way, many potential users, don't understand the role and the importance of the method and the tools of the Design of Experiments (DoE) in the process of development of products, services and production processes.

This paper has as objective to discuss how the use of methods and tools of the Statistical Design of Experiments can contribute in the Project Management with focus on the efficiency of the Development of Products, Services and the Production Processes.

This paper used the methodology of bibliographic research in order to conduct the study. To conduct the research, many bases of data were researched in order to search for papers and books about the themes of Project Management and the Project of Experiments.

The paper is structured in 5 sections, where the Section 2 deals with the Project Management, the Section 3 explains the role of Experiments in the development of products, services and production processes. The Section 4 briefly describes the method and the tools of the Project of Experiments. Finally, in the Section 5 are presented the Findings of this paper.

### PROJECT MANAGEMENT

The globalization of the economy, allied to the competition and the technological advance, forced the organizations to think again in ways to guarantee their surviving in the market. Factors like price, quality and schedule are decisive in the choice of the customer when choosing for a particular product, service or process.

Considering the high demand not easily met, because of the shortage of resources and by restrictions, like the operational costs related to the production processes of products and services. In order to find a better use of the resources, it's important for the organizations the search for the continuous improvement of the processes, including the Project Management for the development of products, services and their production processes. Such development must have as objective the search of the operational efficiency and the overcoming of the competition and the environmental restrictions, by the improvement of the systems and the management of projects. It must be done in alignment with the concretization of the Strategic Planning of the organization, assuring the stakeholders expectations, guaranteeing the

profitability of the business and a competitive advantage in the market [2].

The Project Management methodology became better understood in the second half of the 20<sup>th</sup> century, even knowing that there are registrations in history, of big scale projects since the Egyptian Pyramids 4500 years ago [3]. According to the modern concept of the Project Management, each project is characterized as a temporary effort to create a product, service or result [4]. According to ISO 10006 [5], a project is an unique process, consisting by a group of activities coordinated and controlled with beginning and ending dates, undertaken to reach a goal. This way, it is possible to differentiate that the PMI does the concept of project as the creation of something exclusive to give to clients, besides that, ISO 10006 focus in the process to reach the goals [6]. The Project Management is defined by the Project Management Institute [4] as the application of knowledge, abilities, tools and techniques to the activities of a project, in order to fulfill the requirements, with the purpose of matching to the scope, time and cost of the project.

To carry out a good project of a new product isn't a easy task. With successive shortenings in the time-to-market, the intense competition in saturated markets and with costumers more and more demanding, the organizations must carry out trade-offs when identify priorities to the projects and allocate resources [7]. Even though the conception and the development of the product are only the early stages in the life cycle of a product, the importance of that process on the project and development is such, that the taken decisions during this stage will have a big impact in the final cost of the product.

The conception and development of new products constitute one of the most important and complex activities of and organization. Researches reveal that the failure in the launch of new products varies from 40% to 75% [8]. Researches reveal that 46% of the invested resources by the organizations in conception and development of new products to the market, are badly allocated, and consequently they don't reach the desired results [9]. This way, considering the cost involved in the project and development of new products, the minimization of this tax have big importance to the performance of the organizations.

A great number of researches are trying to identify the key-factors for the success and for the failure of products and projects and they show faults in the definition of requirements and ineffective management as the main causes of the failure of projects [10].

Considering the importance of the Project Management and the demand of the organizations for knowledge in this area, it's increasing the availability of methods to the Project Management, that, for its turn, uses a series of knowledge's and techniques yet established and well known, that are being updated year after year as a result of the conduction of many projects.

Among the methods of Project Management, it's pointed by the Project Management Institute (PMI), that puts together professionals that are looking for the promotion of the professionalism and the development of the state of art in the Projects Management, establishing the acceptance of it as a subject and a profession [6]. The spreading of the knowledge generated in the PMI is made by means of the Project Management Body of Knowledge (PMBOK) that illustrates the best practices for the Project Management. In order to attend the requirements to the success of the project, the collection of knowledge's of the Project Management uses the practices that can be applied in any

project, and they are categorized in nine areas of knowledge [4], listed below:

- Integration – The management of the integration must make that the other eight areas of knowledge to work harmonically and in a correct way. The effort of the integration must make compensations between conflicting alternatives and objectives, since in practice the success of the Project Management, defined in distinct ways, can overlap and, not always they interact in the expected way.

- Scope – The management of the scope must define and control what is and what is not included in the project, dealing with the necessary processes to guarantee that the project includes all the work to obtain success at the end of it.

- Time – The management of time is composed by processes that must guarantee the end of the project on time. The processes of management of time, such as their tools and techniques, vary for the area of application.

- Cost – The management of the costs of the project deals with the processes of planning, estimate, budget, and costs control, in a way to guarantee in the end of the project the approved budget. The management of costs also has to consider the effect of the decisions of the project on the cost of use, maintenance and support of the product, service or result of the project.

- Quality – The management of the Quality of the project includes all the processes of the performing organization that determine responsibilities, objectives and the politics of quality, in such a way that the project attends to the necessities that motivated its realization. The Quality Management System is introduced by means of a politics, of procedures and processes of quality planning, quality guarantee, and quality control, with activities of continuous improvement of the processes from the beginning to the end.

- Human Resources – The management of human resources is focused in the organization and in the management of the project's team, and it's composed by functions and responsibilities attributed to reach the success in the end of the project. However, it is interesting that the members of the team will be involved in a big part of the planning and of the decisions' making, strengthening the commitment with the project.

- Communication – The management of the communication deals with the process that must guarantee the generation, collection, distribution, storages, recuperation and final destination of the information about the project in an opportune and right way. The communication affects the whole project, and everyone in the project must be conscious of that.

- Risks – The management of risks has as objective to increase the probability and the impact of the positive events, and to reduce the probability and the impact of the negative events. A risk may have one or more causes, and if it happens, one or more impacts. If any of these uncertain events occur, it may have an impact in the cost, schedule, quality or performance of the project.

- Acquisition – The management of the acquisitions of the project consists of the processes of purchase or acquisition of products, services or external results to the project's team, necessary to the realization of the work. They also include the processes of the management of contracts, necessary to administrate the contracts or requests of purchase issued by and external organization (client) that is acquiring the project of the executing organization (supplier).

All the mentioned processes, components of the nine areas of knowledge of the Project Management, interact among them, and this interaction can occur with a process of the same area of knowledge or of a different one. It is possible that each process involves the effort of only one person or more people, according to the necessity [4].

### **THE ROLE OF THE EXPERIMENTS IN THE DEVELOPMENT OF PRODUCTS AND PROCESSES**

The conduction of the activities of the development and manufacture of products, processes and or services, focusing in carrying out the expectations of the clients, is not an easy task. Knowing that what makes the development of products, processes and/or services so difficult is the influence of many factors that affect their characteristics. Frequently, such factors are interactive in a way so far unknown and without registration that explain the effects of those interactions, and with this several uncertainties bloom about the future performance of the products, processes, and/or services; this can result in future problems for quality and reliability. Such problems are natural in the development of products and processes, since in the process of development, it is wanted that the reaching goes beyond the limits of knowledge. However, the development of new products needs to have decision making about the specifications of the products and processes, involving the complex interactions among the factors that affect the quality, cost and time to market of the product.

Some interactions among the factors that affect the product can be known by the theory or by previous experiences of the designers, but generally, most of the interactions need to be determined by means of experiments, in a way not to make decisions based on intuition and, this way, increases the uncertainties on the performance of the product. So, it highlights the importance of the experimentation in the development of products, where it can be done in the testing of materials, new ideas and concepts, the improvement of the performance, strength and as a way to improve the reliability [11].

The need of experiments can vary since a simply test up to complex experiments with several factors. As difficultly a simple unitary test will be satisfactory, there's the challenge of conducting the complex experiments with several factors, in a way that the quality of the product will be optimized and the time and cost of the development of the product will be the less possible to allow to the product to be the most competitive possible.

There's a vision that the use of experiments only have more importance in the testing stage of validation of the prototype. But it can't be ignored the valuable opportunities of using the experiments in many phases of the development of the products, because one of the major functions of the experiments is to generate knowledge about the alternatives in the project.

It is a known fact that in the concept phase of the project and development of new products, it is defined the great majority of factors that will determine the costs on the products and its components. So, the choices and decisions taken in the initial phases of the development of products are difficult or demand many resources to be modified in subsequent phases. With this scenario, the best opportunities for the development of products with lower cost, shorter time of production and with better quality and reliability, are in the initial phases of the development of the product. Considering that the level of knowledge about the product is increased by the

organizational assets of the processes, as the process evolves in time, the taken decisions in the initial phases are based on less information than in the subsequent phases of the project and development.

According to the standard ISO 9000 [12] the taken decisions must be based on concrete facts and one way to obtain data that will support the decisions focusing the efforts on the conduction of experiments on the phases of conception and development of the prototype. But, experiments can involve the investigation of the effect of the multiple variables involved in the performance of the product and, so, its highlight the risk of not detecting the effects of the variables, but also in the identification of which variables have significant effect on the process. In the identification of the significant variables and their effects, it's important the use of the Design of Experiments.

### **DESIGN OF EXPERIMENTS**

Design of Experiments (DoE) is the denomination given to the statistic method that investigate the effects in the outputs (Y) of the process, with the controlled variation of the inputs (X) of the process [13].

With the obtained results it is possible to make and analysis that allow to characterize, optimize and discover faults of the process under analysis, that can lead to data that allow decisions that will lead to a better conduction of the controlling of the process.

The Design of Experiments uses the factorial design of experiments, that are used in experiments involving several factors and this situation would require a high number of experiments in order to investigate the effects of the factors in the process, but that high number of experiments would cost material, human resources and time. So, it's necessary an initial study for the identification of the factors that are really significant for the process and once it's done, is conducted the investigation of the unitary and interactive effects of these factors in the variable of the output [14].

Considering that the Design of Experiments is a method and that it doesn't substitute the technologies involved in the process, or the technical knowledge inherent, to obtain success in the conduction of the experiments designed by the DoE, the variables involved, first of all, must be selected and critically reviewed. This analysis must be done by professionals that have the technical knowledge about the process in question, the factors (inputs) that can be controlled and that can present a significant influence in the outputs of the process, such as defining the levels of variation of the chosen factors to be analyzed by means of the DoE. This way, it is possible to make conclusions about the effects of the factors and their real influence in the process. The strategy of experimentation consists in establishing planned changes in the inputs to observe the corresponding changes in the outputs [15].

According to Bishu et al. [15], there are three principal fields of the Design of Experiments: the classical or traditional method, the Tagushi method and the Shainin method. The traditional method, that is the base for the Tagushi and the Shainin methods, uses the factorial  $2^k$ , where k represents the number of factors studied in the experiments, where all k factors have two levels, called high level (signaled by +) and low level (signaled by -) disposed in a orthogonal matrix. The experiments of the design of experiment can be complete or fractioned, where a replication of a measurement is constituted by 2k experiments in case of a complete factorial experiment, and in case of a fractioned factorial experiment it uses a

fraction of the complete matrix. The complete factorial are those in which all the factors, such as all the interactions among them are analyzed in the experiment, one interaction occurs when the effect of one factor in the variable answer is dependent of the level of another factor.

For a process with 3 factors (inputs), to the conduction of the experiment with a complete factorial matrix, it will be necessary to carry out  $2^3$  experiments, or, 8 measures. But in practice, most of the processes are influenced by several factors, and in spite of a complete factorial matrix already brings a big reduction in the number of experiments, if each factor was measured among the levels of operation varying a factor by time, the realization of complete factorials would be unfeasible when the resources are limited. So, frequently, fractional factorial design of experiments are used. The disadvantage in this utilization of fractional factorial design of experiments is that as on this planning it is extracted a fraction of the complete matrix of experiments, it is reduced the quantity of experiments necessary to carry out the study, and with this, its lost the possibility to evaluate and estimate with precision some of the effects of the interactions involved in the process, in a way that each effect of interaction among factors will be confused with some principal effect or interaction [13].

In the complete factorial design of experiments, it's possible to measure the effects of all the factors involved and of all the interactions among the factors studied in the experiment. In the meantime this technique requires a great quantity of experiments that as said before, in many cases, becomes unfeasible because of the quantity of resources necessary for its conduction [13].

The rationale for the use of the fractioned factorial design of experiments, even with the impairment of consistency of the generated analysis, happens because of the interactions can or can't be relevant for the process in study. For such assessment, technical knowledge of the process will help to consider the decision for the utilization of an complete or fractioned factorial experiments matrix. If the technical knowledge allow affirming that in certain process the effects of the interactions are not significant, and that only the factors themselves are significant for the analysis of the process; so it's better to choose for the fractional factorial experiments design.

The factor that determines the level of the degree of confusing in an experiment is what is called experiment resolution, where in an experiment with resolution III there is no confusing of the principal effect with other principal effects and the principal effects are confused with double interactions. In the design of experiments of resolution IV, there is no confusing of the principal effect with other principal effect or double interaction. Double interactions are confused with other double interactions and in the design of experiments of resolution V, the double interactions are confused with triple interactions. Depending on the number of factors in the analysis it is possible to analyze  $n-1$  factors, where  $n$  is the number of experiments that were carried out [16].

After carrying out the experiments of the design matrix and after the analysis of the measured results, it can be obtained the equation of the variable answer, being possible to estimate with certain precision, and answer to the response to the process. It is also possible to determine the adjustment of the factors in study in a way to obtain a maximized, minimized or determined optimized answer.

A project and development can have a focus on making a product more robust to the variation under the effect of uncontrolled variables (noise). Knowing that what

determines the difference between success or failure of a product is the way the project team of the product deals with the variables that can't be controlled. This way, one of the biggest forces of the robust project is in the ability to deal with variables that can't be controlled (noise), in a way that the product maintain enough quality, even if the uncontrolled variables reach unfavorable values to the product.

## FINDINGS

Considering that the world market lives a moment of increasing demand, that is not easily supplied, because of the relevant operational costs and the implementation of enterprises, it is necessary that the organization continuously develops their process, including focus in the process of the Projects Management and development of products.

A way to carry out a good project of a product and considering that this is not an easy talk, because of factors like successive shortenings in the time-to-market, fierce competition in saturated markets and consumers more and more demanding, the organizations must carry out trade-offs to identify priorities to the projects and allocate resources. Even that the project and development of the product is only one of the phases of the life cycle of a product, the importance of the process of project and development is such that the decisions taken during this stage will have more impact in the final cost of the product.

Knowing that a mistake in the launch of a new product varies between 40% to 75% and that 46% of the resources invested by the organizations in the project and development of new products to the market are badly allocated, consequently some desired results are not reached, and considering the cost of the resources spent in the project and development of new projects, the minimization of this tax is of great importance to the performance of the organizations.

As, in the conceptual phase of the project and development of new products, it is in this phase that are defined the great majority of the costs of the product and its components, the choices and decisions taken in the initial phases of the development of products are difficult or demand many resources to be modified in the subsequent phases. Considering that fact, the best opportunities to the development of products with lower cost, shorter time of production and with higher quality and reliability, are in the initial phases of the development of the product (conception).

In the search of using experiments in a way to provide the project team with information about the factors that influence the process and products characteristics, and the effects provoked on them, it is possible to point the use of the Design of Experiments with the following benefits of its use in the development of products and processes:

- 1) Simultaneous optimization of several factors that affect the process, in a way that the Design of Experiments can increase the efficiency of the activity of the experimentation in the development of new products. This way the answers obtained in the analysis of the experiments carried out using the method of the Design of Experiments can reduce significantly the quantity of necessary experiments and consequently the inherent cost of the necessary resources to the experiments execution, what also results in less time to collect data, helping the quick decision taken in the initial phases of the development of the product; so it can represent a competitive advantage in reducing the time-to-market.

2) Reduction of costs and improvement of quality, in virtue of the accurate selection of variables of the process or parameters of the project that will be responsible not only for the improvement of the products quality, but also for the reduction of production time and costs. Even if it is detected that a referred factor does not have significant influence in the process in a way to improve quality, it can be used to study the influences of this factor in the reaching for a more feasible configuration, considering the costs and production time.

3) It is important to highlight that the method of the Design of Experiments also allows to analyze the effect of the uncontrolled variables, also called noise, in a way to minimize the variation caused in the variables of the answer (outputs), by the variation of such external factors, allowing to reach for a project that considers such uncontrolled variations and look for a minimizing the undesirable effects, leading to a more robust product.

4) The method of the Design of Experiments brings to the process of project and development of the product a systematic and well defined so that the designers and developers won't lose the target on identifying the variables that are really important, in other words, that have a considerable effect in the outputs of the processes and in the final product, allowing, this way, to determine the best conditions for such variables.

Based on such conclusions, it is evident that the use of the method of the Design of Experiments has a great potential to contribute in the Project Management, since it gives a structured method for the conduction of the experimentation, in a way to provide data that will allow the decision making, based in facts and that can lead to a more competitive product in terms of quality, production time and costs.

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