# IMPROVING A PROCESS IN A BRAZILIAN AUTOMOTIVE PLANT APPLYING PROCESS MAPPING, DESIGN OF EXPERIMENTS AND DISCRETE EVENTS SIMULATION

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#### ABSTRACT

The objective of this article is to apply the Design of Experiments technique along with the Discrete Events Simulation technique in an automotive process. The benefits of the design of experiments in simulation include the possibility to improve the performance in the simulation process, avoiding trial and error to seek solutions. The methodology of the conjoint use of Design of Experiments and Computer Simulation is presented to assess the effects of the variables and its interactions involved in the process. In this paper, the efficacy of the use of process mapping and design of experiments on the phases of conception and analysis are confirmed.

Keywords: Design of Experiments, Discrete Events Simulation, Process Mapping

# 1. INTRODUCTION

As an example of conjoint application of simulation and design of experiments, the work of Nazzala, Mollaghasemi and Anderson (2006) can be cited, as it integrates simulation, design of experiments and economic analysis in a decision-making process at a semiconductors company, using a simulation model validated according to techniques presented by Law and Kelton (2000), Nayani and Mollaghasemi (1998), and Sargent (1998).

The benefits of the design of experiments in simulation include the possibility of improving the performance on the simulation process, avoiding the trial-and-error techniques to seek solutions. Kleijnen, Sanchez, Lucas and Cioppa (2005) affirm that research related to design of experiments is frequently found in specialized magazines, rarely read by simulation practitioners.

Thus, the objective of this article is to apply the design of experiments techniques along with the discrete events simulation technique in a process of an automotive industry. The effect of the input variables (number of ungrease machine, number of shifts and numbers of works) over the output variable (total of parts produced per day) is intended to be evaluated. Moreover, the effects of the interaction between the input variables through full factorial design is also intended to be assessed.

### 2. COMPUTER SIMULATION IN MANUFACTURING ENVIRONMENTS

According to Harrell, Ghosh and Bowden (2000), and Law and Kelton (2000), simulation is the imitation of a real system, computer-modeled, for evaluation and improvement of its performance. In other words, simulation is the importing of reality to a controlled environment where its behavior can be studied, under various conditions, without physical risks and/or large costs involved. Banks (2000) affirms that simulation involves the creation of an artificial history of reality and, based on this artificial history, observations and inferences on the operating characteristics of the real system that is represented can be made.

O'Kane, Spenceley and Taylor (2000) affirm that simulation has become one of the most popular techniques to analyze complex problems in manufacturing environments.

According to Banks, Carson, Nelson and Nicol (2005), simulation is one of the most widely used tools in manufacturing systems, more than in any other area. Some reasons may be enumerated:

- The increase in productivity and quality in the industry is a direct result from automation. As automation systems become more and more complex, they can only be analyzed using simulation;
- The costs with equipment and installations are huge;
- Computers are becoming cheaper and faster;
- Improvements on simulation software reduced the time of development of models;
- The availability of animation resulted in higher comprehension and usage from manufacturing managers.

### **3. DESIGN OF EXPERIMENTS**

The word experiment is used in a very precise form to indicate an investigation where the system under study is under control of the investigator. On the contrary, for an observational study, some characteristics will be out of the control of the investigator (Cox and Reid, 2000). According to Montgomery (2001), the experiment can be seen as a test, or as a series of tests, in which the proposed changes are applied on the input variables of a process or system, to, then, observe and identify the changes occurred on the output variables.

Still according to Montgomery (2001), the design of experiments refers to the process of planning of experiments in a way that appropriate data can be analyzed through statistical methods, resulting in valid and objective conclusions. According to Kelton (1999), one of the main goals of the experimental design is to estimate how changes in input factors affect the results, or answers of the experiment.

Some terms are commonly used in design of experiments. Mason, Gunst and Hess (2003) define factor as a controllable experimental variable, which variation influences the response variable. Each factor must assume some values, defined as levels. The changes occurred on the mean of the values of the response variable correspond to the effects.

Besides the effects caused by the factors, the effects created by the interaction of the factors can be determined. These interactions correspond to combined effects, where the effect of each factor depends on the levels of the other factors.

The decisional process of the experimentalist falls back on a trade-off between performance versus cost, where the necessity of a more precise recognition of a greater number of factors and interactions bears a larger number of experiments and replicates.

According to Cox and Reid (2000), the advantages of the use of a full factorial lies on the higher efficiency in estimating the main effects of the factors under the variable in analysis, and, specially, the definition of the interaction among all the factors.

According to Sanchez, Moeeni and Sanchez (2006), many studies related to operations management use the full factorial design of experiments because of its simplicity and due to the fact that its project allows the analyst to identify interactions among the factors, as well as the main effects. As examples of these studies works from Enns (1995), who used the factorial design to evaluate the usage rate and sequencing techniques in a process can be mentioned. Malhotra and Ritzman (1994) considered a full factorial design to evaluate the impact of demand variability, usage capacity, and route flexibility in postal service stations.

The disadvantage of the use of the full factorial lies on the amount of time and experiments to be made. According to Kelton (1999), when the number of factors becomes moderately large, the number of experiments explodes. A possible solution for this situation is the use of fractional factorial, in which only a fraction of all possible combinations are evaluated. This solution is indicated to situations where a great number of factors to be analyzed exist, where only the main effects of the factors are considered important.

The realization of the experiments is frequently expensive or even impracticable. For these situations, the use of simulated experiments is recommended, and this integration between design of experiments and simulations is presented as follows.

# 4. DESIGN OF SIMULATED EXPERIMENTS

According to Kelton (1999), the use of simulation aids directly the execution of experiments that are costly or even impossible to be carried out in practice. Still illustrating the conjoint applicability of design of experiments and simulation, Barton (2002) points out in his work that, typically, simulation researchers emphasize the realization of experiments on the simulator and the analysis of the responses obtained, not paying attention to a previous phase to this one, where the planning of the experiment to be carried out must be made, with the possibility of being carried out in practice through Design of Experiments (DOE).

According to Kleijnen, Sanchez, Lucas and Cioppa (2005), many simulation practitioners could obtain more information from their analysis if they used statistical theories, more specifically with the use of design of experiments developed specifically for computer models.

To understand the role of simulation in the execution of experiments, it is only necessary to imagine that, in an experiment, the response variable (RV), or dependent variable, can be represented as: RV = f (IV), where IV represents the input variables (independent variables). Thus, according to Kelton (1999), the transformation function f represents the simulation model itself.

Nowadays, simulation software accompanies generators of random numbers. So, according to Kelton (1999), from the design of experiments point of view, it is possible to excerpt the experimental randomization that frequently corresponds to a hard problem in physical experiments. Another important verification is that, when the execution of the experiments occurs in a simulation model, all the input factors became controllable. Barton (2002) emphasizes this statement affirming that nuisance variables rarely appear in simulation models, because normally, there is control over all other factors.

Another important advantage of the use of simulation in the execution of experiments is replicating the experiments many times, obtaining many estimates of the main effects and interaction of the factors. These replicates will favor the conclusion of the significance or non-significance of the effect. Frequently, physical experiments are made in a small number of replicates, or even without them, due to the experiment difficulty or even the cost involved. These limitations do not occur in simulation once the model is constructed and validated. Dessouky and Bayer (2002) integrated the selection of the maintenance policy in the process construction phase, through simulation (software ProModel 4.0) and application of DOE, through the Taguchi technique.

In this research, 4 factors (problem severity, maintenance policy, resource capacity and validation time) and 2 levels were defined. The experience of the specialists and the system knowledge were used to define the factors and variables.

Schappo (2006) presents an analysis of an assembly process of compressors and cellular layout alternatives, making use of design of experiments techniques and computer simulation as an analysis tool of the different scenarios with the objective of quantitatively measuring the changes introduced on the system which is being studied, improving the performance indicators in the manufacturing process as well as productivity increase.

In the opinion of Kleijnen, Sanchez, Lucas and Cioppa (2005), most projects were originally developed for experimentation in the real world, and they have been adapted to be used in simulation studies, instead of being developed specifically inside the simulation principles. Classical texts of design of experiments, such as Box, Hunter and Hunter (1978), Box and Draper (1987), Montgomery (2001), Myers and Montgomery (2002), focus not on the necessity of simulation analysts, but on the practical restrictions and conduction of experiments in the real world. Other texts about simulation such as Law and Kelton (2000) and Banks, Carson, Nelson and Nicol (2005) cover a vast array of topics on the subject; however the demonstration of design of experiments is done using simpler problems that do not stimulate the mental abstraction of readers about the deepness and application possibilities.

Therefore, it may be affirmed that practitioners of simulation must be attentive to the use of experiment projects as a necessary part of the analysis of complex simulations.

# 5. METHODOLOGY

According to Silva and Menezes (2005), a research is experimental when an object of study is determined, variables that would be capable of influencing it are selected, and ways of controlling and observing the effects that the variable produces on the object are defined. On this experimental research, the experiments will be carried out through a discrete events simulation.

Using an analysis of the simulation methodology proposed by Chwif (1999) and the steps proposed by Montgomery (2001) for design of experiments, a flowchart that tries to explain the logic of the simulation process was constructed, in which the experimentation phase is conducted by DOE. This research was conducted according to the methodology shown in figure 1. In this methodology, there are three models that must be made: the conceptual model, the computer model and the operational model. In the same manner, these models must be validated or verified. According to Law (1991), the creation phase of the conceptual model is the most important aspect in a study of simulation. Chwif and Medina (2006) dedicate special attention to this model, since, according to them, many simulation researches do not demonstrate this stage. According to Shannon (1975), an effective conceptual modeling can lead to the identification of an adequate solution, avoiding the necessity of a complete simulation study. Works such as Greasley's (2006) use process mapping as a means of describing the logic and determining decision points, even before the computer model, created in the software Arena®.



Figure 1: Methodology of Conduct of this Research Montevechi, Pinho, Leal and Marins (2007)

In this paper, the conceptual model will be the starting point, supplying information to the computer model. The representation of the conceptual model will be made in the form of a process mapping, executed using a selected technique. According to Leal (2003) and Pinho, Leal and Almeida (2006), these techniques must be selected according to the characteristics of the process and the objectives of the work. Besides, the generated maps must not be characterized as an end, but as a feasible means for visualizing improvements.

In this research, the process map will be used, which, according to Barnes (1982), is a technique to register a process in a compact way, through some standardized symbols like operations, transports, inspections, delays and warehousing. The level of detail achieved by this technique is compatible with the objective of this research. Moreover, it is a well-known tool, which facilitates the validation process of the conceptual model, along with process specialists (real system).

The computer model is obtained through conversion of the conceptual model using some simulation language or a commercial simulator.

The simulator selected for this work is Promodel<sup>®</sup>. Hlupic and Paul (1996) present a methodological approach to select the simulation software, according to some criterion, as cost and processing time. The reasons for choosing this software for this research are due to, above all, the use of graphic animation, an important ally in the verification and validation of the model. In the same manner, works from authors such as Verma, Gibbs and Gilgan (2000) justify the use of Promodel<sup>®</sup> due to the possibility to analyze the simulation through the accompaniment of the animation, being easy to apply and interpret.

After the elaboration of the computer model, it must be verified whether its behavior is according to the conceptual model. This process is called model verification. The verification also consists of eliminating bugs from the model.

After obtaining and verifying the computer model, it must be submitted to various runs obtaining, this way, results in different scenarios. These results must be compared with the results of a real system, in order to verify the size of the error. Once the error is inside the acceptable limits, the model is apt to execute experiments, called operational model.

# 6. APPLICATION OF THE PROPOSED METHODOLOGY

The way the steps of the proposed methodology of the above item were conducted during this research will be described as follows.

Step 1.1: Objectives and system definition

The objective of this work is determining which variables, among the selected, have more influence over the total daily production of the system. The three analyzed variables were: number of ungrease machine, number of shifts and numbers of works. These variables were selected because they were pointed out by the specialists of the real system as strategic.

First it was chosen a case from an automotive industry. The final product of this company is a ring which is used in the automobile engines. The model that will be elaborated is classified as a discrete event simulation.

The study case is related to a manufacturing cell disposed at the beginning of the production process. This cell is responsible for the manufacture of the first part of the production process. Eight machines and two workers are used in the manufacturing cell which works along three shifts. Each worker is able to operate two machines which are used to feed other two machines and also to transport components inside and outside the cell. The workers involved in that job are also responsible for the inspection of the products and to set up each machine.

The simulation time was 18 days (three weeks), with three shifts (8 hours each).

#### Step 1.2: Construction of a conceptual model

In this phase, the real model under investigation is summarized using the conceptual model, which is simply a series of logical relationships relative to the components and structure of the system.

This conceptual model won't be demonstrated in this article, for solicitation of the company.

# Step 1.3: Validation of the conceptual model

The validation was realized through comparison between the process mapping and the real situation. The mapping, realized by the researchers, was presented to the process specialists and to people from the company not directly related to the real system. This way, once verified that the system is correctly represented, the conceptual model is registered.

#### Step 1.4: Modeling of the input data

For the realization of this work, the software Promodel® from Promodel Corporation was used. It is one of the most used softwares on the market (Doloi and Jafari, 2003). This package incorporates three main programs: Promodel® (for simulation of discrete events), SimRunner® (for the optimization of optimization models), and Stat::Fit® (for probability distribution studies).

The processing times were measured in the object of study and inserted in the software Stat::Fit® with the objective of obtaining the candidate probability distributions and the adherence test.

#### Step 2.1: Construction of a computer model

For the construction of a model, ProModel® presents the following elements: places, entities, resources, processing and arrivals. The definitions and the functionality of the main elements are shown as follows:

Places: Represent the fixed places of the system, where the processes are carried out. These elements are used for the representation of workstations, buffers, conveyors and waiting lines. In this element, capacity, units (simple or multiple), setups, maintenance, statistical detail level and rules for the arrival and departure of materials can be defined.

Entities: The entities are items to be processed by the system, and they can be: raw material, pallets, people, or documents. The entities have defined speed, besides having statistical level like the places. They can be grouped or divided along the productive process, being moved from one place to another using a defined route or a work network.

Variables: Can be global or local. The global variables are used to represent mutable numeric values. The local variables only establish functions in the part of logic in which they are declared, and both can contain either numerical or real values. A global variable can be referred to in any place of the model. On the other hand, the local variable can only be referred to inside a determined block where it has been declared.

Attributes: Similar to the variables, the attributes are attached together with entities and specific places and usually contain information about them. They can contain real or whole numbers. From its usage only one entity referring to one type of part can be created and seven attributes to differentiate the seven types of parts to be modeled, as occurs in this paper.

Arrivals: Defines the input of the entities inside the model. The quantities, frequency, arrival periods as well as the arrival logic can be defined. Also, the arrivals through an external arrival file of parts referred to in the file editor can be defined.

Processing: Consists of a table where the operations of each entity in each place as well as the necessary resource for this operation, and a table of routes that determines the destiny and movement of each entity as well as the way in which this movement happens and the necessary resources are defined.

Resources: Are the elements used to transport entities, execute operations, and make place maintenance. They can be either people or equipment. A system can have one or more resources, endowed with movement or not. However, for each mobile resource a path network must be designated, that is, a route in which movement will happen.

Figure 2 illustrates the construction environment of the computer model from ProModel®.



Figure 2: Environment of the Computer Model from ProModel®

#### Step 2.2: Verification of the computer model

This model was verified by the following procedure: the model was built in stages; twenty versions were constructed; only when the model of each stage was working correctly the new stage could be initialized. Furthermore, at the beginning only deterministic data was used to simulate the model. This kind of data makes easier for the user to check if the logic is corrected in the model. Also, the debugger of ProModel®, the software used to perform the simulation, pointed out to the researches some mistakes. The tests runs were performed with the animation function working. This function allows the user to verify the inconsistencies in the parts flow.

After that, stochastic values were used in the computer model.

#### Step 2.3: Validation of the operational model.

Before using statistical techniques, a face to face verification was applied. In this verification the model was introduced to the company specialists. Using animation these specialists could evaluate the model working. In this verification the model was accepted.

In the analyzed case, the variable used for comparison represents the number of parts manufactured in one day. The statistical distribution that best fits this variable behavior is a Poisson distribution.

Bisgaard and Fuller (1994) said that in works with design of experiment the response is typically measured in a continuous scale. However, in many cases the unique economic useful measure is to count the numbers of defects or defected parts. Almost every statistical method, particularly the methods applied on the factorial experiment analysis, is based under the assumption that the response is measured in a continuous scale and has constant variance. According to the authors, derivations show that it is possible to obtain a constant variance to defects counting using square root over the collected data, in the case of a Poisson distribution.

Applying the square root function in the real and simulated data, it is possible to verify if the new data can be represented by a normal distribution.

Figures 3 and 4 show the normality test performed using the Minitab Software in the real and simulated data.



Figure 3: Anderson-Darling Normality Test for Simulation Data



Figure 4: Anderson-Darling Normality Test for Real Data

In this test, the p-values found were 0.460 and 0.565. Both are greater than 0.05 then it is possible to consider as a normal distribution.

After the real and simulated data were considered as a normal distribution, it is possible to perform the Ftest. The F-test is done comparing the variance between the system and the model data. The null hypothesis is the one which the variances of both data (from the real system and the model) are equal. The alternative hypothesis is the one which the variances of both data are not equal.

Figure 5 shows that the null hypothesis should be rejected. This test was done using Minitab.



Figure 5: Variance Similar Test

Once the variances are not equal the option highlighted in the figure 6 should not be selected.



Figure 6: t-test for Dissimilar Variance

Following with the test using Minitab, the t-test is accepted since the p-value is 0.079 greater then  $\alpha = 0.05$ . Thus the model is a good representation of the real system according to the statistical techniques.

Step 3.1: Definition of Experimental design

The factors selected for the work correspond to those the team defined as most probable of having contribution in the total amount of parts produced by the system.

Factor A: Number of ungrease machine: This factor expresses the amount of ungrease machines.

Factor B: Number of shifts: This factor expresses the amount of shifts.

Factor C: Number of workers: This factor expresses the amount of workers.

In summary, the experiment planning is as follows:

- Number of Factors: 3;
- Number of Levels: 2;
- Number of Experiments: 8;
- Number of Replicates: 3.

Table 1 shows the experimental conditions for the described experiment.

Table 1: Experimental Conditions

Factors	Level -	Level +
A:	1	2
B:	2	3
C:	2	4

Step 3.2: Execution of the Experiments

Table 2 shows the experimental matrix for the experiment planning described on step 3.1. In this table, r1, r2 and r3 mean replication 1, replication 2 and replication 3. The replications values mean total amount of parts produced by the system.

Table 2: Experimental Matrix

	Α	В	С	r1	r2	r3	
1	-	-	-	104000	91000	104000	
2	+	-	-	104000	104000	104000	
3	-	+	-	104000	104000	65000	
4	+	+	-	91000	78000	78000	
5	-	-	+	104000	78000	117000	
6	+	-	+	91000	78000	78000	
7	-	+	+	104000	104000	117000	
8	+	+	+	104000	104000	104000	

Step 3.3: Statistical Analysis

The analysis of the main effects of each factor, presented in figure 7, shows that factor C (number of workers) has a strong positive effect over the final response, that is, the daily amount produced. This means that the alteration of level (-) to level (+) increases the final result. That factor A (number of ungrease machine) has a strong negative effect over the

final response. MiniTab® was the software used for the developed calculations.

The weight of the effects can be visualized in figure 8. On this graph, it can be verified that just BC factors interaction effect (number of shifts \* number of workers) are significant for a degree of confidence of 95%, as shown by cutoff line for statistical significance.



Figure 7: Graph of the Main Effects



Figure 8: Pareto Chart of the Standardized Effects

Step 3.4: Conclusions and Recommendations

The factors B and C isolated do not have a significant effect on the response variable. However, as showed in the previous item, the interaction between these factors has a significant effect on the response variable. This effect could be hardly verified by specialists without the use of design of experiment.

#### 7. CONCLUSION

The use of Design of Experiments conjointly with Computer Simulation allowed a more efficient analysis of the results of the simulated model. Moreover, the significance of the effects of the interactions were confirmed, aiding the managerial decision making process.

It is also important to emphasize that the process mapping technique made possible the creation of the conceptual model in the conception phase of the used methodology, as shown in figure 1. The same way, the Design of Experiments technique made possible a more meticulous analysis in the analysis phase.

It is good to emphasize that the experimentation phase on the simulation should be preceded by the verification and validation phases. In this current case the statistical validation guarantee that the output data from the simulated model might represent the behavior of the real system.

For the company, the recognition of the individual and combined effects of the factors favors the elaboration of an improvement plan for the increase of the daily production rate. Since the productive process is dynamic, that is, it is altered according to market demand, knowing the most relevant factors of this process facilitates the decision making, about the factor levels, by the managers.

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