Applying virtual simulation in automotive new product development process*

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Abstract: The objective of this paper is to analyze the impact of virtual simulation use on Product Development Process (PDP). A comparative analysis was made between PDP "Traditional Model" (a name used specifically in this work for product development without virtual tools); and the updated PDP (process which uses virtual simulation to analyze the project before physical prototype build up and testing). The research methodology approach was the case study used in the automotive sector. Analyses were carried out based on documents and data research with professionals involved in PDP activities and virtual simulation. The data research was done using two structural questionnaires; interviews were conducted with Directors and Managers from Product Engineering. According to the theory study and case study results the proposed questions were answered, discussing the advantages and restrictions of virtual tools.
Keywords: product development process, virtual simulation, physical prototype, computer aided design, (CAE)

1. Introduction

Due to the global and dynamic environment in which companies are inserted, Product Development Process (PDP) is an important factor to gain competitive advantage. Companies are investing on new technologies and processes to guarantee quality and reduced costs to the project.

The advance in computational technologies allowed the implementation of new development and validation processes by virtual tools introduction. Virtual tools application shows an opportunity of better PDP, with impact on costs and implementation timing.

In this work, a critical analysis of simulation use on PDP was performed in an automotive company.

This paper presents, in sections 2 and 3, respectively, the new product development process (NPD) and virtual simulation literature review. Section 4 presents the methodological approach adopted. Section 5 presents the case study results. Finally, the last section presents the conclusions.

2. Product development process (PDP)

According to XU (1998), PDP "traditional approach" is based on the following cycle: project, physical prototype build up and testing as presented in Figure 1. The testing phase is a kind of mistake and correction cycle, corresponding to a development and learning process, as well as product validation. If the project is not adequate, corrections are made based on experience; consequently, the process becomes long due to physical prototype verification for any corrections made.

It is important to highlight that the denomination of PDP "traditional approach" used in this paper, means PDP without virtual tools use.

According to CLARK & FUJIMOTO (1991), there are several physical prototypes types that can be applied for product development and validation. In the initial phases of PDP, prototypes parts can be built up with alternative materials (denominated mock-ups); mechanical prototypes that represent the product only partially (this kind of hardware does not represent the final body structure and form) allowing analysis such as steering, brakes and suspension, reproducing the vehicle handling and riding. These prototypes are the first opportunity for physical analysis, after that; there is a complete prototype that represents the final product.

Initial prototypes are low cost and demand less time for building up; on the other hand, the final prototypes are extremely expensive and demand a long time for building it up, but they are much more representative.

A comparison among three different physical prototypes in several criteria is shown in Table 1.

In the automotive sector, the cost of a complete prototype represents a high cost because it is built up with specific devices and tools for building and assembling a reduced number of vehicles.

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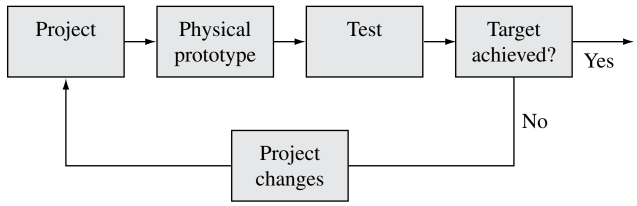

Figure 1. PDP "traditional approach" (Adapted from XU, 1998).

Table 1. Physical Prototypes comparison (Adapted from CLARK & WHEELWRIGHT, 1992)

	Clay model	Mecanical prototype	Complete prototype
Cost			
Cost	Low	Medium	High
Timing	Low	Medium	High
Representativeness			
Form	High	High	High
Assembly	Medium	High	High
Functionality	Low	High	High
Material	Low	High	High
Process	Low	Low/medium	High

As PDP "traditional approach" is a learning tool, in which corrections and optimizations are made based on physical prototypes results, several cycles of project, building up and testing are required until the target required for the project is achieved.

The result of this sequence is high cost and a long period to introduce a product in the market.

3. Virtual simulation in NPD

PDP "new approach", denomination applied in this paper to PDP that uses virtual simulation for project analysis, emerged in the 1970s. At that time, computational activities in automotive industries were limited to engineering digital drawing. In the 1980s, great investments were made on CAE systems; the focus had changed to activities such as tests simulation and advanced engineering. The simulation programs created perspectives of dynamic tests execution without the need of physical prototypes, creating possibilities for cost reduction and increase in test alternatives (CLARK & FUJIMOTO, 1991; CLARK & WHEELWRIGHT, 1992).

However, in the late 1980s, a high number of physical prototypes used in order to validate projects in the automotive sector was verified; the engineering prototype remained as the main tool of validation, even with the progress of computational technology. The difficulties were related to computational capability, as even the most advanced computers showed problems to generate complex system simulation (CLARK & WHEELWRIGHT, 1992).

The virtual tools were widely spread in the 1990s. In the beginning of that decade, the PDP cycle was still composed of a sequence of physical tests, but in the middle of the decade the PDP had reduced the number of prototypes with the inclusion of virtual tests. At the end of the decade, a full phase of physical prototypes could be excluded from vehicles development process due to the advance and confidence acquired on virtual validation (ROHDE, 2001).

Several factors allowed the intense use of virtual simulation in the 1990s (RYAN, 2000):

- finite element models and three-dimensional solid models were available for most system components;
- the recent technology simplified the component model representation allowing an efficient process in simulation systems;
- graphic workstations became cheaper and more complete;
- data management system allowed a large amount of information, updated and available in the network;
- due to virtual simulation tools, physical prototypes, tests and project corrections cycles are gradually being substituted by virtual analysis (ROHDE, 2001); and
- the literature presents the factors related to technical and organizational issues that impact on simulation implementation success.

KROUSE (1999) also highlights the following items:

- high quality input data, including parameters such as friction coefficients, pivot locations, input loads, part masses, bushing stiffness and centers of gravity for individual parts. The author recommends the building of database to allow quick access to information;
- cultural and organizational issues have to be solved; people used to traditional procedures may be reluctant to change or may feel threatened by new technology. And sharing data between groups can spark territorial disputes and disagreements over data ownership. The best strategy for addressing these sorts of problems is to get people involved as early as possible in the implementation of virtual prototyping; and
- investments for hardware, software, networking and training to guarantee high quality of CAE infrastructure.

In addition to the above items, MURPHY & PERERA (2002) mention some aspects related to knowledge as critical success factors. These authors also make some recommendations in order to improve the success of virtual simulation in organizations, as the following: a) to develop and to use effective mechanisms of promotion to spread the awareness, visibility and benefits of simulation as an important business tool, throughout the company; b) to actively share knowledge and experience among all simulation users; and c) to utilize in-house expertise to form the simulation team allowing simulation experience to be retained within the company.

This research focuses on virtual simulation software application, concerning the evaluation of new products performance. The computational simulation is understood in this paper as a logical math model development process of a real system and experimentation of this model using computers.

Thus, the simulation is the model creation process, project and implementation of an adequate experiment to represent a real system (PRITSKER, 1986).

One of the most widely used methods for dynamic tests simulation is the finite elements method. This method was initially developed for structural analysis but the application was extended to several areas such as thermal analysis, fluid dynamics, noise and vibration.

The basic concept of simulation by finite element method is divided into three steps:

- **first step:** The finite element model is made using a tool that allows the capture of geometric information from CAD; this form is divided into discrete elements. So, the finite element model is the geometric representation of the region in study;
- **second step:** Input of data related to boundary conditions of the region in study, representing external influence such as moments, velocity and force; and
- **third step:** The model is processed according to boundary conditions by a calculation system called solver, giving the results of the simulation test that will be visualized by a specific tool.

4. Field research design

The qualitative methodological approach was chosen to answer the central questions related to the development of this research, due to required involvement in the organization context and focus (YIN, 1989). The empirical field research was developed through case study based on a framework extracted from the specialized literature.

The main purpose of this paper was to analyze the impact of applying virtual simulation in product development process (PDP). Two questions drive the data collection of the field research:

- how can virtual simulation benefit NPD process?; and
- what are the main constraints to virtual simulation application in NPD process?

Thus, this research focuses on the virtual simulation software application, concerning the evaluation of new products performance and validation. Furthermore, this research intends to obtain analysis of the gap among the traditional prototype and the virtual one in terms of reliability and quality, not only on time and cost bases.

The main criteria to select the case were the following: growing investments in virtual simulation software application; strategic importance of new product development (NPD); and the mixed use of PDP "traditional approach" and "new approach". Based on these criteria, a subsidiary of a multinational belonging to the automotive sector was selected.

Several sources of information were used in the case study analysis as suggested by several authors (BONOMA, 1985; EISENHARDT, 1989). The analysis was done based on documents and interviews with professionals involved on PDP activities and virtual simulation, as well as top managers, as summarized in Figure 2.

The data collection was conducted with two different questionnaires; the first one applied to directors and managers from the studied company and the second one applied to product engineering professionals. Both research instruments were developed based on the theoretical framework.

The first interview process was more informal and based on a sequence of unstructured questions that allowed free comments by the interviewees. This questionnaire was applied to Simulation and NPD managers aiming at getting information related to specific simulation tests. The second type of interview was more formal and composed by structured questions. This questionnaire was applied to Managers and Directors in order to identify the Product Engineering point of view about simulation use.

The documents used for evidence analysis were: physical and simulation test reports, standards and procedures.

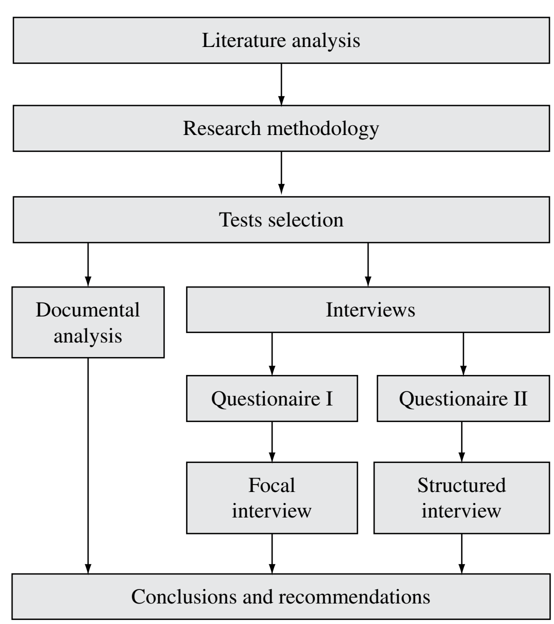

Figure 2. Research framework.

Due to numerous tests available, some were chosen to be studied in this case. Some criteria were applied to select the tests, in order to guarantee the understanding of simulation use as a physical prototype substitute:

- **criteria 1:** Tests applied on physical prototype and virtual simulation, allowing comparison between data such as cost, timing and performance between these two modalities;
- **criteria 2:** Tests applied in similar projects, allowing comparative analysis of timing and cost; and
- **criteria 3:** Tests related to different level of capability and confidence simulation.

5. Case study analysis

This section presents the main results of field research in the studied company, concerning test documental analysis and interviews.

The case study was carried out in a subsidiary of a multinational large size company belonging to the automotive sector.

5.1. The documental analysis

The documental analysis was based on physical test report, simulation test report, legal standards, procedures and simulation methodologies.

The documents mentioned allowed comparison between virtual simulation and physical tests, making possible the analysis of simulation capability and capacity.

Table 2 shows data from documents; the difference between virtual simulation and physical test is shown by percentage.

Table 2 shows that virtual simulation tool can be applied to several tests and there are different levels of capability and confidence of simulation.

The simulation test related to water intake is done by qualitative analysis that shows the water flow in the region of air admission.

The under body temperature test depends on physical prototype data such as exhaust temperature, so only with this information is it possible to generate good results on virtual simulation. Consequently, for this specific test the simulation does not eliminate the physical prototype, but can reduce the cycles of physical evaluation.

Roof Crush and stiffness simulation tests represent with good precision the physical test procedure allowing more physical prototypes substitution.

Table 2. Physical prototype and simulation comparison

Test	Difference between simulation and physical prototype
Roof crush	<10%
Side crash	<15%
Body temperature (under floor)	<10%
Water intake	Qualitative analysis only
Stiffness	<5%

5.2. Interviews analysis

The data collected from interviews allowed the identification of simulation constraints of physical prototype substitution, as well as the benefits that can be achieved by applying virtual simulation.

As already mentioned, the first step was the focal interview with Simulation Managers. The data made clear the reduction in cost and time for all tests selected when simulation instead of physical prototype was applied. Table 3 presents the comparison between time and cost Due to information protection, the side crash test was used as a comparative base.

By focal interview, the constraints of physical prototype substitution were identified. Table 4 summarizes the main constraints.

The second step of field research was questionnaire 2, in which questions related to benefits and difficulties of simulation use were applied to Managers and Directors of Product Engineering. Figure 3 shows the agreement degree of virtual simulation benefits based on NPD professionals' perspective from the studied company.

Figure 3 shows that more than 70% of interviewees agreed with all listed simulation benefits, for instance, reduction in cost and time, better quality, previous problem identification and better simultaneous work.

According to this input, it is possible to conclude that the analysis unit is aware of simulation benefits and there

Table 3. Time and cost comparison

Test description	First physical prototype (%)	First virtual simulation (%)
Time		
Roof crush	41	17
Stiffness	41	17
Side crash	100	17
Water intake (engine compartment)	25	2
Body temperature	25	2
Cost		
Roof crush	90	43
Stiffness	90	43
Side crash	100	43
Water intake (engine compartment)	36	2
Body temperature	36	4

Table 4. Restrictions for physical prototype substitution.

Tests	Restrictions
Roof crush	Legal requirement requires validation by physical prototype.
Side crash	Simulation method limitations. Legal requirement requires validation by physical prototype.
Stiffness	No restrictions.
Water intake (engine compartment)	Missing simulation software to represent the case.
Body temperature	Missing correlations with physical prototypes. Difficulties to obtain input data.

is a positive posture related to simulation use on project development and validation.

Questionnaire II allowed getting data related to difficulties and constraints of applying simulation based on professionals' perception, as shown in Figure 4.

The field research conducted by questionnaire II indicated that "Missing software & Missing physical and virtual correspondence" was the most voted restriction factor for effective use of simulation as physical prototype substitution tool. This result is in accordance with questionnaire I output, where it was detected that specific tests such as side crash and water intake have the following simulation restrictions: simulation model restriction and missing software.

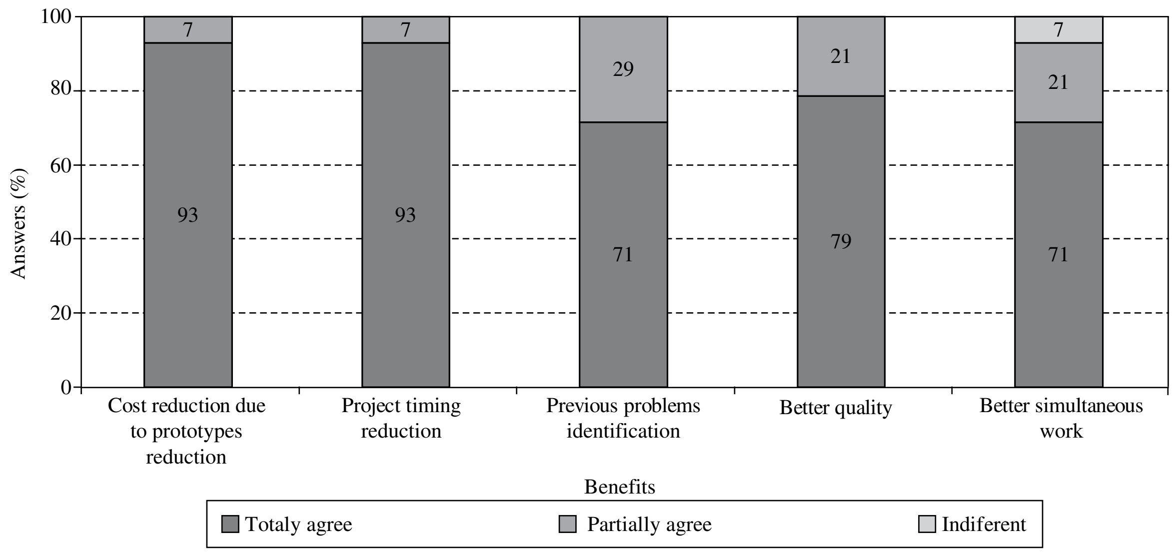

Figure 3. Virtual simulation benefits.

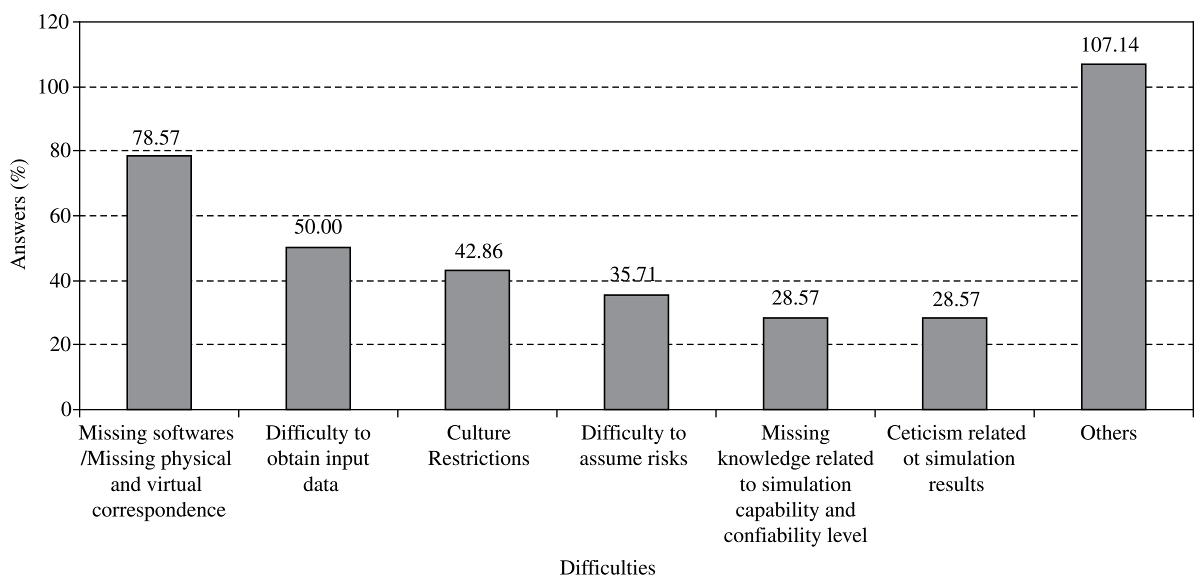

Figure 4. Virtual simulation: difficulties and constraints.

The item “Difficulty to obtain data” was classified by 50% of interviewees as a restriction factor; this result is also in accordance with results from questionnaire I, where the difficulty of data collection was identified for the following test: body temperature.

The third most voted item by NPD professionals was culture restrictions, the habit of developing and validating products by physical prototypes hindered the migration to virtual simulation use.

6. Conclusions

The first analysis is related to the following question: How can virtual simulation benefit NPD process? This research question is related to the assumption that virtual simulation contributes for costs reduction and time of project implementation. The case study confirmed the benefits of simulation by evidence colleted. The documental analysis compared physical tests and virtual simulation results showing the level of confidence and capability of each test previously selected, concluding that all tests have the potential of physical prototype reduction, but in different proportions, reflecting less costs and time for project validation.

The results drawn by questionnaire I confirmed the benefits of applying virtual simulation in terms of cost and timing comparison between physical and virtual prototypes. Furthermore, questionnaire II also confirmed the benefits of simulation by interviewees’ perception. Finally, the theoretical review confirmed the benefits by the following authors: KROUSE (1999), CLARK & WHEELWRIGHT (1992), CLARK & FUJIMOTO (1991).

Besides costs and time reduction, other benefits related to simulation were identified, such as: better quality, previous problem identification and better simultaneous work between different departments. These benefits were also identified by field research and confirmed by the theoretical revision.

The second analysis is related to following question: What are the main constraints to virtual simulation application in NPD process? This research question is related to the assumption that the effective use of simulation is also a cultural issue.

The theoretical review (KROUSE; 1999; MURPHY & PERERA, 2002) as well as the field research results (questionnaire I and II) also confirmed this second assumption. However, the interviews and theoretical review showed others factors related to simulation usage success besides cultural issues.

The main constraints indicated by NPD professionals in the studied company and supported by literature (KROUSE, 1999; MURPHY & PERERA, 2002) to applying virtual simulation were the following: a) missing software and simulation models limitations; b) difficulty for data input; c) culture issues; and d) missing knowledge of simulation confidence and capability level.

Analyzing both assumptions, it is possible to conclude that the benefits of simulation go far beyond costs and time reduction and have huge importance in NPD process. Some evidence of NPD enhancement through virtual simulation could be found such as a reduction of both development cycle time and development cost. It was also possible to analyze the virtual simulation benefits and the restrictions for physical prototypes reduction.

There was a lack of evidence in quality issue in some virtual validation test in the studied company. Finally, no relationship could be stated about the effects in the number of new products launched.

In conclusion, the agenda for future studies should encompass the identification of virtual simulation priorities in the automotive sector, aiming at physical prototypes reduction by effective use of virtual simulation. Furthermore, the development of a virtual simulation database that shows the confidence and capability level of each kind of validation test seems to be necessary in order to monitor the evolution of simulation and to spread its practice in the organization.

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