PRODUCT DEVELOPMENT PROCESS ASSITED BY DFX – DESIGN FOR EXCELLENCE TOOLS

Luis Alberto Brêda Mascarenhas, breda@cimatec.fieb.org.br
Luciano Santos Azevedo, lazevedo@cimatec.fieb.org.br
Sabrina Oliveira Caribé, scaribe@cimatec.fieb.org.br
SENAI CIMATEC – Integrated Centre for Manufacturing Technologies

Luís Gonzaga Trabasso, gonzaga@ita.br
ITA – Aeronautics Institute of Technology

Abstract

In the competitive environment of the product development companies, the implementation and the use of support design processes tools became an enterprise survival condition. In this context, this article analyze and correlate the main tools/techniques used in Product Process Development (PDP) and its stages of Process Development cycle, being identified by applicability, advantages and disadvantages of the use of each one of them. For achieving such a goal , a brief description was carried through the PDP stages and the most used of these tools and techniques, such as: DFM – Design for Manufacturing, DFA – Design for Assembly, DFS – Design for Service, DFQ – Design for Quality; DFSS – Design For Six- Sigma; DTC – Design to Cost, KBE – Knowledge Based Engineering and QFD – Quality Function Deployment This work also presents a real case study the Nano car. The Nano car was developed by Tata Company and is the cheapest car in the world. It is analyzed which solutions and DFX techniques were used to obtain that outstanding results.

Keywords: *Knowledge Based Engineering, Product Development Process, DFX, DFA, DFM.*

1. INTRODUCTION

Right from the beginning, humankind looks to develop more efficient tools and methods to meet theirs goals as people and as nation. In the 90`s, a formal and structured Product Development Process (PDP) became a competitiveness condition to maintain companies alive. The PDP can provide the customers desires, identifying or creating customers needs and help companies to make products for providing such needs. The discussion to develop a new product linked to the market needs involve people from different companies department and teamwork with multidisciplinary skills and integrated product process development FACHINELLO, T. (2004) apud CLARK & FUJIMOTO, 1991; PATTERSON, 1993; ECHEVESTE, 2003; CUNHA et al. (2003).[1]

The PDP is a business processes in constant improvement, which require discipline to be applied, FREITAS, C. (2004). The PDP concept was used in the companies as one the most important process to support the consolidation their position in the competitive market, where is necessary constants innovations, FACHINELLO, T. (2004). In this case, two aspects are important, the time to launching and the product innovation level. The companies have to realize the correct time to input their product in the market and at the same time warranty the product innovation.

PDP had some important changing as the way to manage its activities. VALERI, S. G. (2000) apud FLORENZANO, (1999) sad that the Product Development Process has the interface between customers needs and companies products, and the products must support the following requirements: (1) be oriented to the customers; (2) quality felled by the market; (3) manufactured before the concurrent; (4) with reasonable cost and (5) easy manufacturing. [1]

As FREITAS, C. (2004), the way a company work is defined, independent if they do service or manufacture products, but by the competitiveness level and the concurrence they are exposit. In a general way, the companies will work depending on: productive concepts; marketing aspects and the risk to develop a new product are proportional to a product complexity.

FREITAS, C. apud WILLIAN apud OLSON (2001) say that with a higher complexity level, the project risk rise exponentially. They mention that it can identify issues at the beginning or even at the end of the project, but, for sure, if identified at the end, the damages will be bigger. figure 1 shows the product cost that was compromised during its developing life cycle. On the other hand, figure 2 shows the changing cost during the main steps of a launching product.
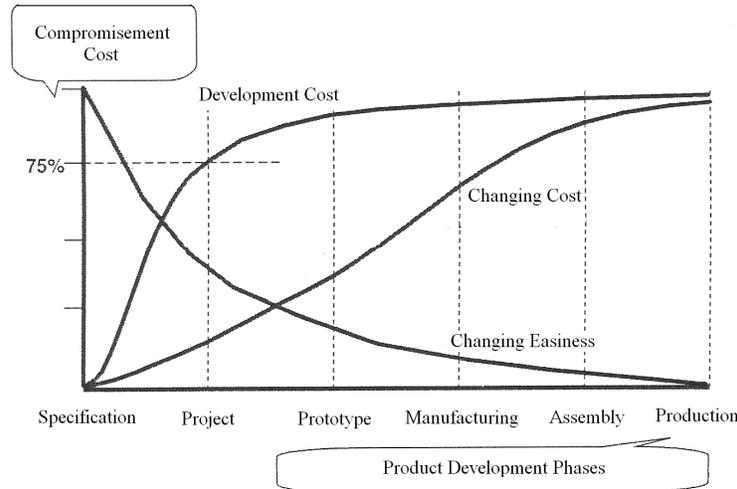
Figure 1 – Compromised Cost During the Developing Life Cycle.
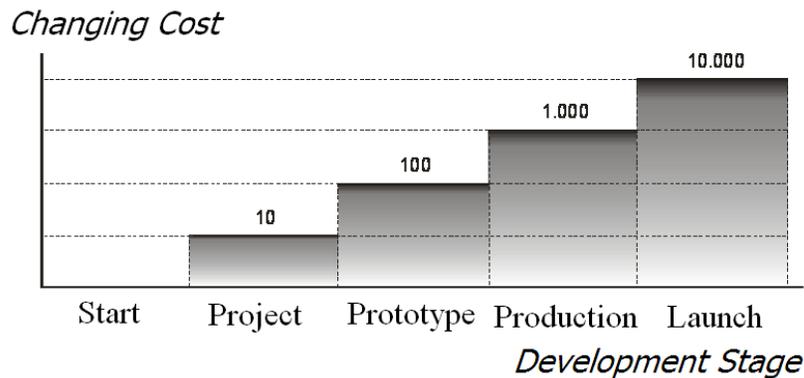
Figure 2 - Changing Cost During The Main Steps of a Launching Product.

Considering that the main steps on the PDP are: (1) Specification; (2) Design; (3) Prototypes; (4) Manufacturing; (5) Assembly and (6) Production, it can be observed in figure 1, that 75% of product costs were determined in the first step. So, late changing will be difficult to do and certainly will be more expensive.

Then PDP aided tools were developed to be applied in all process phases. It enable that the phases can be monitored and evaluated to drive the product to the market and improve the companies results.

The objective of this article is to show the most used aided tools that help the product development process and matching them (tools and development phases). At the end also is presented a real case that is the Nano Car, produced by Tata Company for less than US$ 2,500. In this case, the aided tools were analyzed and related to the car design.

2. APPLICATION ANALYZE OF THE DFX TECHNIQUES IN THE PRODUCT DEVELOPMENT PROCESS

ROSENFELD, H. (2006) define Product Development as united activities that want to support market needs, considering the actual technologies and companies interest, by the product specifications and its manufacturing process, answering to costs and quality. [2]

Normally, PDP were done in a serial way, where each step was alone, the team interaction was few, with time for start and end of each phase and the production was forgotten until the last project stages. In this case, a changing caused by manufacturing limitation generates a cost, not previewed, that could make the product unfeasible.

With the principles of Integrated Product Development (IDP) or Simultaneous Engineering (SE) this situation was change. The phases became more tight and integrated at the same process and viewed as part of a cycle where the

decision could be reviewed and the information could be feedback fast on the process. The team that was considered isolated change to teamwork with a unique objective and the customer requirements are now analyzed during all IDP.

As FREITAS, C. (2004), in the IPD there are a lot of parallel activities and process been doing at the same time. VALERI, S. G. apud CLARK & WHEELWRIGTH (2000) divide the IDP in four different phases: Conceptual Development; Product Planning; Product or Process Engineering and Pilot Production. However, ROSENFELD, H. et al (2006) share IDP in five main phases: Informational Project; Conceptual Project; Detailed Project; Preparation for Production and Product Launching (figure 3). Others authors separate the process in some different ways, but there are not significant content differences. Then, for this work the Rosenfeld model was used as reference. [1].
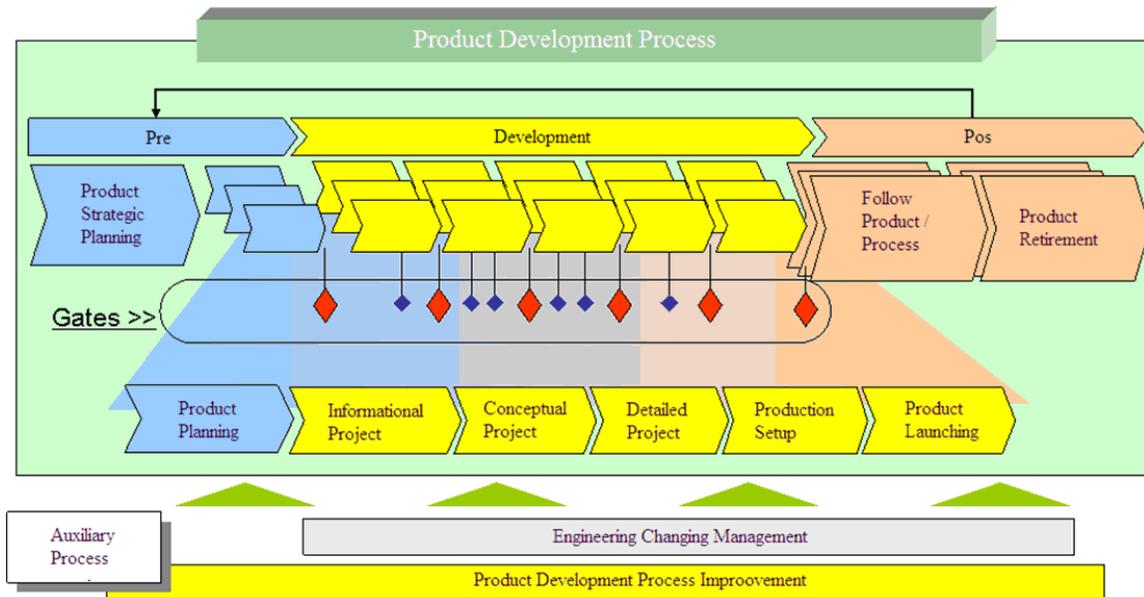
Figure 3. Product Development Process by ROSENFELD.[1]

For all this process a lot of structured techniques give support to the take decision and step process validation.

Nowadays, customers want much more than only price. The price can be monitored and enhanced by the correct application of techniques like DFM – Design for Manufacturing; DFA – Design for Assembly and Design for Cost, for example. Because the concurrence and to have customer fidelity the product must have others attributes that are good looking by the costumer, as more reliability, less time to repair and so on. In this new scenario new "Design For" techniques were created. To BRALLA (1996) this kind of techniques are a base of knowledge to close customers desires and companies strategies. [3]

The DFX - Design for Excellence techniques are applied in the steps of the product development cycle to associate to the product best fit characteristics to the next steps, like manufacturing, assembly, logistics etc. Figure 4 shows some of the most important DFX techniques.
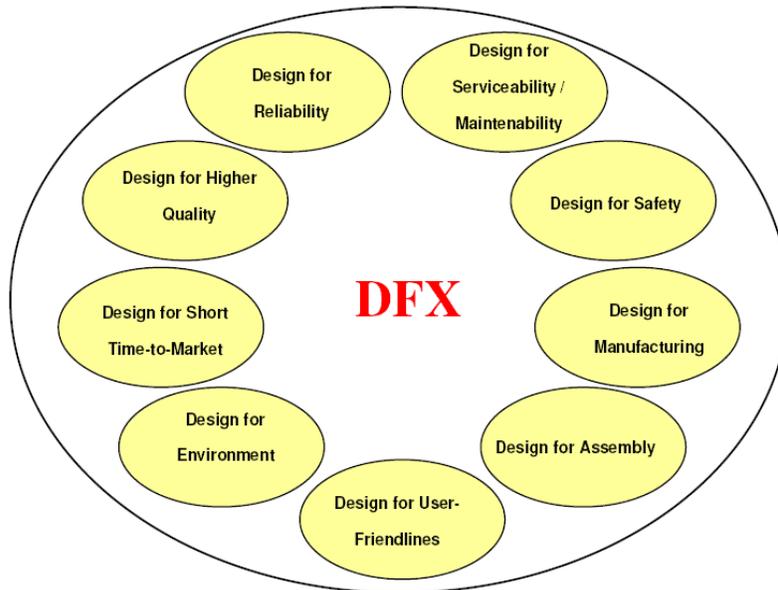
Figure 4 – Some of the most important DFX techniques.

Some concepts, applicability, vantages and disadvantages for the main DFX techniques, considering the most used in the technical literature are summarized below.

2.1 DFM – Design for Manufacturing and DFA – Design for Assembly

The objective of the Design for Manufacturing (DFM) method is to consider in the conceptual stage information from the manufacturing step for they drive the necessary changes to make the product easy to be made and cheaper to be made, with the same functions. The changes that normally happen in this stage are related to specification, handling material, quality control, assembly and material processing. [4]

The main DFM guidelines are presented bellow

- To reduce the number of parts;
- To use the modular concept;
- To use standard components;
- Design peaces for multiuse;
- Design peaces for easy manufacturing;
- Avoid fastener parts;
- Design an unidirectional assembly draw;
- Use bezel, guides and the gravity to make the assembly easy;
- To reduce handling;

The objective of the Design for Assembly (DFA) is to optimize the project to make the assembly easier, faster and cheaper. Some typical examples are presented as follow: change de project to reduce the number of peaces; joints without fasteners, like screws and rivets; add some characteristics to the peaces, like bezel, conic cylinders, stops etc, that could help the assembly process; creation of a assembly sequence, using the gravity to help the assembly and not the opposite. A brief cost comparison can show how it is important. The screw cost and a cost for assembly the same screw. The assembly process is six times expensive than the screw cost. One of the ways to measure how the process is optimized is measure the time to assembly the peaces and the united.[4]

These both techniques can help the integration between product development area, manufacturing area and the assembly area in the way to prevent problems in the manufacturing and assembly stages.

In a quick view the DFA software analyze the product's parts searching for unnecessary parts or those that could be integrated into others and also try to optimize the component cost, assembly time, people cost, total assembly cost and the necessity of investment.

As Boothroyd; Dewhurst (1994) "*Manufacturing*" should be understood as an operation to manufacture an individual component and "*Assembly*" is a simple operation for assembly more than one component to create a final product or a subsystem. Then, DFM and DFA should be applied with different objectives. However, is very common use these both techniques together, when the best results can be obtained.[4]

Some application software were developed to help the companies to apply DFM and DFA. This software help the people on material selection, manufacturing process, estimating the manufacturing cost, estimating component cost etc.

DFM and DFA major use is applied to the conceptual project and detailed project. Changes in the detailed project normally cause changes in the conceptual project. This cycle improve the product quality. Suggestions to simplify the product's structure, materials, more economic process are even more simple, it means, the cost to that changes in this phase are lower than in the subsequent phases. This is one of the most important goals for teamwork.

The difficulties to implement DFM and DFA techniques are related mainly to the people barrier – fear to change, expressed as limited time to product development process; excessive care to analyze and speak about projects made by others; superficial analyze for the phase that have not relevant cost and so on.

2.2 DTC – Design to Cost

In the Product Development Process cost is an item very important as technical parameters and shall be considered during all product development cycle. So, is necessary to use methods to optimize and put the costs under control. DTC is applied to the product development with focus on costs control, following the formula:

$$MC = SMP - SMG$$

where, MC is the Market Cost; SMP is the Selling Market Price and SMG is the Selling Market Gain.

The objective of this method is to improve the product performance, searching to be close to the Market Cost (MC), it means, to introduce product changes to balance the function realization, maintaining the cost around the component and product Market Cost.[5]

This tool is applied during the PDP and should be always remembered at the materials selection, specification of the production methods, search of solutions and others that could define the product viability. At the conceptual phase is necessary have in mind the profit level expected by the stakeholders and balances all changes that could move the final price to up. In this way, is necessary to define the mark cost at the development planning. This cost can be understood as life cycle product cost who shall be satisfied at this phase.

The decision toke in the conceptual phase is responsible for 75% of the total product cost. Basically, under an economic point of view, this decision occurs where functional structure takes place.

The main vantages and disadvantages when applying Design To Cost Method are shown below.
Vantages:
- Optimize the functional product performance, by adding new characteristics on the systems and subsystems;
- Product cost reduction;
- Detailed knowledge about components and product cost;
- More accurate felling about how much the customer evaluate the product;

Disadvantages:
- Necessity to evaluate the customer felling about each product function;
- At the cost analyze, some initial ideas could be off, nevertheless could be more creative.

2.3 DFS – Design for Service

The DFS is a method who has focus on maintenance characteristics improvement. Then, the effort is driven to ensure that the products reduce the maintenance necessity. The maintenance dimensions could be considered as: reliability; maintenance and less maintenance necessity. The changes on the process and product who are normally used are: ergonomic improvement on the service repair; product with simple repair, who does not need specialized people; use of standard parts, reduction the number of spare parts; improvement of the access to the peaces that require constant maintenance; system that help easy and fast trouble identification, reduce the number of special tools, lower time to repair and so on. There is a technique that is used to enhance these objectives that is the FMEA – *Failure Mode and Effects Analysis.*

DFS use some rules that can help the teamwork:
- Rise the reliability – this attribute contribute to reduce the maintenance need;
- Design products that wear parts are easy visible, hence the time to repair will be lower;
- Design products in modules that could be exchange. So, the maintenance could be very fast.

2.4 DFQ – Design for Quality

DFQ is applied to the product development cycle and the objective converge to improve the product quality, understanding that the product quality could be translated by attributes, defined by the costumer, it means, the customer recognize some product parameters as satisfaction. These attributes could be measured, for instance, by robustness (failure resistance); reliability (less necessity to be repaired); performance and price. However, for a design oriented to quality is necessary to be clearly defined which are the stakeholders requirements. This method could use some tools like: tolerance design, where the manufacturing tolerance are calculated and defined by the product application.[1]

DFQ method application during the product development process is done using some quality tools as QFD – Quality Function Deployment. QFD tool is used to warranty the requirements fit to the customers needs.

2.5 DFSS – Design for Six Sigma

The Design for Six Sigma is a method that is used for product and process development could be made thinking in the customers needs with six sigma quality, it means, reducing the errors, defects and failures.

To apply this method all people from the teamwork must know the DMAVD and IDDOM. Also is important that the board of the company be involved, defining responsibilities, authorities and activities. The most used technology is the DMADV who has five clear steps:[11]
- Definition – objective identification that have to be enhanced;
- Measurement – customer needs understanding;
- Analyze – define the better option among the alternatives;
- Project – Develop the complete product design and
- Verification – Test and product validation.

2.6 KBE – Knowledge Based Engineering

The KBE method is not a common DFX technique. However, it has a characteristic to promote a structured way to use the knowledge learned in preview projects in new developments.

KBE is a technology to retain the knowledge with the objective of improves the company competitiveness. The KBE allows the companies to catch and to deploy the knowledge and the experience from its engineering teamwork, best manufacturing practices, law, cost and others rules. KBE is been used by several companies in the world and some in the Brazil, as Embraer. One of the major benefits from this technology is time reduction and cost reduction for project, while at the same time improve final product performance, quality and price.

KBE produce more benefits by improve velocity and product development process effectiveness as a whole. The generative KBE module produce direct gain by reduce new products time creation. The time reduction is obtained in each project phase by eliminating repetitive tasks. However, is necessary to consider that for KBE technology

application it depends of a specific computational tool and it is necessary extra budget to fill this tool and, mainly, catch correctly the project feeling from designer and engineers. [6]

The application of a KBE technology provides a structured project approach. The geometry generation can be automated, been controlled by specific rules and codified by a KBE development engineer. It allows to users to give more focus on others activities to product development and improve the answer to the customer functional requirements. The KBE kernel is the generative and integrative model. The model allows not only change entities from a mathematical parametric model with defined dimensions, but it has engineering rules who determine the product project. The model normally is built using programming language oriented to the object and this architecture allows the construction of a modular model. In general, it allows the application in products and complex systems making them easy to be designed, produced or projected for less maintenance.

When using this tool the engineer inform the functional requirements to new product versions and the KBE can specify data and generate them automatically. These data could include product geometry, manufacturing instructions, cost information, depending how the generative model was built. It means, how more detailed, or how more efficient was the catch of the project intention, better will be the project result. Then, more people could be moved to work in others project steps.

During the creation of the KBE generative model is possible create additional rules to produce views for alternative models for a lot of product development tasks, for example: finite element mesh; process planning; cost planning; automated CAD model creation, and so on.

The main benefits from KBE are:
- Product development time and effectiveness improvement. There are cases where the reduction for product development time was from weeks to hours;
- Project cost reduction;
- Repetitive project activities reduction;
- Fast feedback to teamwork.

In a general way KBE is a powerful concurrent engineering tool who can help product development time reduction, decreasing product development cost and decreasing also the final product price.

The difficulties to apply KBE are related to human aspects and software aspects, as follow: [6]
- It is necessary a high employees commitment level to a precise catch of the way to design;
- It is necessary a high people support level;
- It is necessary a high investment. It is impossible start a KBE without a specific computational tool;
- Human aspects. It is mandatory a communication strategy to let clear which are the objectives and how the company wants to manage the launch program.

2.7 QFD – Quality Function Deployment

QFD is a simultaneous engineering tool to warranty that the customer and stakeholders needs drive product project and product production. This tool identifies user requirements and defines process definitions to the manufacturing, in a way to measure the project and product quality to keep to the customer satisfaction. QFD is more adequate to be used for complex products, as for them, it is more difficulty to identify what is relevant to the costumer. QFD application start from customers needs to identify system requirement, then it is possible to define components characteristics, manufacturing process and manufacturing operations. These steps are built using four matrixes co-related, they are: matrix 1 – product specification; matrix 2 – system parts; matrix 3 – process planning and matrix 4 – production planning.[9][10]

The QFD method is applicable to all product development cycle. Table 1 shows a relation from a method application (matrixes) and product development phases. Also is presented the objective of each matrix.

Table 1. Relation between QFD Matrixes and Product Development Phases.

Matrix	*Matrix Function Description*	*Product Development Cycle Phase*	*Objective*
Matrix 1	Product specification	Informational project Conceptual project	Translate the customer "voice" into product requirements
Matrix 2	System parts	Conceptual project Detailed project	Translate product characteristics into components requirements
Matrix 3	Manufacturing process planning	Production planning	Translate components characteristics into process requirements
Matrix 4	Production planning	Production planning	Translate process characteristics into production requirements

One of the most important vantages of QDF application is to formalize step by step the customer requirements, which shall be present at the final product. This process, as show in Table 1, is done following the 4 steps (matrixes) and the final result depends on the quality of the analysis made in all steps.

The difficult to apply this method is associated to the quantity of information that is necessary to fill completely the four matrixes. Normally, what happened is that only the matrixes 1 and 2 are completely filled, that are related to customer requirements and system parts definition.

3. NANO – Case Study

In the last months all the world car magazines turn its interest to a small car that will be produced in India. The car is the Nano which will be manufactured by Tata Company. What is so different in this car is not a state of the art technology, but the price. Nano is the cheapest car in the world produced in series; it will cost lass than US$ 2,500. It is described herein what the Tata engineers did to enhance this remarkable result, matching solutions, DFX techniques and results as summarized in Table 2.

First, the Tata Owner defined clearly what he believed were the main customer requirements: price, the car shall transport four people; the car shall be economic and the car shall have four doors. Then the engineers were challenged to enhance this goal. An important thing that is worth mentioning is that the most part of the engineers have not experience with car designing, so they had no paradigms to be broken. Then, is easy now to understand some solutions they promoted.

Table 2 – Solutions applied for Nano Car x DFX techniques and Results.[12][13]

Solution	DFX Techniques	Results
Only one window wiper	DTC, DFM, DFA	Cost reduction. Function OK
Tank door off	DTC, DFM, DFA	Cost reduction. Function OK
Break system based on drum, without hydraulic assistance	QFD, DTC, DFS, DFA	Weight reduction (30 kg less), number of peaces reduction, cost reduction
Two cylinder engine	QFD, DTC, DFS, DFA	Weight reduction, number of peaces reduction, cost reduction, car more economic
Painting process needs only one furnace cycle	DFM, DTC	Process is 30% cheaper
Special Spare tire. It is smaller and lighter	DTC	Weight reduction, cost reduction
Mechanical steering	QFD, DTC, DFM, DFA, DFS	Weight reduction, number of peaces reduction, cost reduction
Back door doesn't open. The luggage must be filled by the rears doors.	DTC, DFM, DFA	Weight reduction, number of peaces reduction, cost reduction
Seats are not adjustable	DTC, DFM, DFA	Weight reduction, number of peaces reduction, cost reduction
Instruments panel with basic equipments	DTC, DFM, DFA, DFS	Number of peaces reduction, cost reduction
Only three screws are use to wheel fasten	DTC, DFA	Number of peaces reduction, cost reduction
12" diameter wheels	DTC	Cost reduction, weight reduction

So, they really reached the marks, the car is light (600 kg), is economic (23,6 km/l); carry 4 people and is really cheap (less than US$ 2,500). It is a very good case that proves the powerful of these tools and techniques presented here. Then, if they could do the cheapest car in the world applying some DFX techniques it show that is possible introduce significant benefits to industrial process, product development process, and final product also, it depends on how deep the teamwork go.

4. CONCLUSIONS

From the content present here it is clear that there is a huge potential to improve product development process if the correct methods or tools are applied. Nevertheless, the gain could de even better if some of these techniques were applied in an integrated way. To support this idea a lot of examples could be given, but one who show in a clear way is the gain that can be obtained from KBE method. KBE can provide structured knowledge that was catch from the teamwork and it is put available for similar application. So, the benefit is not repeat operations that are foreseeable. The time reduction with the use of KBE method can be from 5 to 20 times, compared to traditional serial projects. Of course it is not easy to construct this database, not only because technical difficulties, but because the human factors.

Some techniques conduce to contradictory results, like decrease quantity parts and includes redundant components to improve product reliability. So, the best results to the product project are that one that better manage and balance the customer requirements and the functions that the product turns available.

In the other hand, a lot of people from teamwork are resistant to implant some methods. It is normally treated like a "Integrated Product Development Dilemma" that is to apply some techniques and tools in the preview phases from PD, what in an initial analyze compromise the time for this step. However, as the teamwork can have a global view of the development, it means that they will anticipate and solve some problems in forward phases. So, how these problems will not appear, because they were already solved, the global time will be less than in conventional projects, besides the firsts stage were longer than the conventional project.

5. REFERENCES

[1] VALERI, S.G. (2000) Estudo do processo de revisão de fases no processo de desenvolvimento de produtos em uma indústria automotiva. São Carlos, 2000. 109 p. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, Universidade de São Paulo.
[2] ROZENFELD, Henrique [et al.] Gestão de Desenvolvimento de Produtos – Uma referência para a melhoria do processo. São Paulo: Saraiva, 2006.
[3] BARBOSA, G.F. (2007). Aplicação da Metodologia DFMA – Design for Manufacturing and Assembly no projeto e fabricação de aeronaves. São Carlos. 165p. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, Universidade de São Paulo.
[4] GONÇALVES Barros Junior, Jayme. Protótipo de um modelador DFM – Design for Manufacturing – voltado para Ferramentas de Corte 2005. 95 folhas. Tese de Mestrado – Instituto Tecnológico de Aeronáutica, São José dos Campos.
[5] Cristiano V. Ferreira et al, ESTIMATIVA DE CUSTOS DE PRODUTOS SEGUNDO AS ABORDAGENS
DO DESIGN TO COST E DO DESIGN TO MINIMUM COST. II Congresso Brasileiro de Desenvolvimento de Produto. São Carlos-SP (2000)
[6] COOPER, S., FAN, I.S., LI, G – Achieving Competitive Advantage trough Knowledge-Based Engineer, Cranfield University.
[7] MONTGOMERY, D.C. *Design and Analysis of Experiments*. Wiley, 6th Edition.
[8] Cristiano Roos1; Jorge André Ribas Moraes2; Leandro Cantorski da Rosa3 MELHORIA DA QUALIDADE NOS SERVIÇOS DE TRANSPORTE UTILIZANDO A FERRAMENTA FMEA. Universidade Tecnológica Federal do Paraná – UTFPR. 2008
[9] TRABASSO, L. G. – Apostilas utilizadas no curso de mestrado profissional GTEC do SENAI CIMATEC.
[10] FERNANDES, J.M.R, REBELATO, M.G. Proposta de um Método para Integração Entre QFD e FMEA.PUCPR.
[11] Fioravanti, Alexandre. Aplicação da metodologia "Design for Six Sigma" (DFSS) em projetos automotivos/ A. Fioravanti. São Paulo 2006.
[12] A gênese do Carro Mais Barato do Mundo. Revista Exame, abril de 2009
[13]O Novo Carro do Povo. Revista Quatro Rodas, abril de 2009.
[14]Daniel   Capaldo,   Vander   Guerrero,   Prof.   Henrique   Rozenfeld.   Site http://www.numa.org.br/conhecimentos/conhecimentos_port/pag_conhec/FMEAv2.html.