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ENABLING MASS CUSTOMIZATION THROUGH SET-BASED CONCURRENT ENGINEERING

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Abstract: This research purported to discuss the concepts of mass customization in the automotive industry and how the use of lean principles in product development enables a profitable Design and Production customization. The results of a case study performed at an automaker plant in southern Rio de Janeiro state, Brazil, proved the efficiency of the company practice to develop simultaneously multiple concepts for each mechanism or Project detail, with substantial increase in design reliability, reducing redesign, cost, and development time, although cultural barriers were found.

Key-words: product development process; mass customization; set-based concurrent engineering; SBCE; automotive industry.

1 INTRODUCTION

In the last decades, worldwide market changes have imposed unprecedented pressure over companies, coining new challenges to them in a fierce competition environment (SCALA, PURDY, and SAFAYENI, 2006). Demands for better quality, lower cost, technological product updating (ZACHARIA and MENTZER, 2007), growing consumer demand for quick responses, smaller production batches of customized products, shorter product lifecycles, customers' new requirements (LAM and CHIN, 2005), multiple regulatory changes and the constant pressure for innovation obligates companies to continuously develop and offer products and services perceived by customers as value-added opportunities, creating customer-producer links and preventing competitors from getting part of companies' market share (ALVAN and AYDIN, 2009; ROCHA, DELAMARO, and AFFONSO, 2012), what makes the product development process (PDP) a critical success factor for companies (ROCHA and DELAMARO, 2012).

The development of new products, although, involves risks and uncertainty: according to Baxter (1995) and Duber-Smith and Black (2012), out of ten ideas about new products, three will be developed, 1.3 will be launched, and only one will be profitable. Van Kleef (2006) indicated that new product development (NPD) failure rates are between 25 and 67%. Less than 50% of the companies keep production costs within the budget and launched their products on schedule: on average, products cost 13% above the budget and are released six months late (BAXTER, 1995).

Therefore, companies face the challenge to make their PDP flexible, efficient and effective to ensure a strategic position in an environment of rapid change, where decisions no longer can occur on trial and error basis, since changes happen more quickly than the lessons are learned (ROCHA and DELAMARO, 2007). So, the concept of “do-it-right-the-first-time” seems to be a company survival rule. The influence of complexity in determining NPD strategies is a subject that requires effort from Design and Project managers (SPILL, 2012), since organizations must rely on mature processes even in a time of crisis, avoiding the tendency to overcommit, abandon their processes, and, consequently, being unable to achieve and/or repeat their successes (ROCHA, QUINTELLA, and OLIVEIRA, 2013).

Ganghi, Magar, and Roberts (2014) highlight that companies are struggling with a decrease in loyalty after the recession and eager to avoid a painful race to the bottom of the cost curve in globalized and standardized product arenas. In this scenario, companies face a dilemma: how to play safe, developing new products, fulfilling customer ever-changing requirements (sometimes unique requirements) and remain attractive to customers, profitable, and competitive at same time?

The answer to the question may rely on the concept of mass customization, a Design/Production strategy driven primarily by sales and marketing teams that understand the demand for customized products and pass them on to development and production teams. The goal of mass customization is to create individually customized products, with mass production, volume, cost, and efficiency (SMITH et al., 2013), i.e.: “a paradox-breaking manufacturing reality that combines the unique products of craft manufacturing with the cost-efficient manufacturing methods of mass production” (DURAY et al., 2000, p.605).

In mutable environments, with high levels of uncertainty, the constant possibility of flexibility in the product results in better design and products developed (MACCORMACK, VERGANTI, and IANSITI, 2001). Although, even though mass customization becomes almost mandatory, it cannot enable profitable customization by itself. True scale in mass customization can only be achieved with an integrated approach where technologies complement one another across a company’s various functions to add customization value for the consumer, bring down transaction costs and lead times, and control the cost of customized production (GANGHI, MAGAR, and ROBERTS, 2014).

Qudrat-Ullah, Seong, and Mills (2011) stated that the Lean PDP can successfully be applied to improve the operations of a high variable-low volume product mix business, while Al-Ashaab et al. (2013) indicate the Set-based Concurrent Engineering (SBCE) as a key element in the Lean PDP model. The present study hypothesizes that the SBCE is an enabler to the mass customization strategy. Such hypothesis is tested through a case study in a commercial vehicle manufacturing plant installed in the southern Rio de Janeiro state, Brazil. Research procedures, as well as the concepts of SBCE and mass customization, are discussed ahead in this article.

The next paper sections are as follows: Section “Relevance and Context” presents the research justification and its contextualization; Section “Procedures and Techniques” presents the research methodology; Section “Theoretical Framework” comprises the fundamentals of Mass Customization and Lean PDP/SBCE, presenting, also, a brief review of the state-of-the-art about those themes; Section “The Use of SBCE on PDP” highlights the design practices applied by the Design team in the studied company and perceived consequences, mainly on the development of customized vehicles. Finally, at the Section “Conclusions and Remarks”, findings are assessed and discussed, while proposals for additional researches are made.

2 RELEVANCE AND CONTEXT

The design phase represents only 5% of the total costs of developing a product, but established 70% of its operating costs (MILLER, 1993): for example, at Rolls-Royce, the project establishes 80% of the final production cost (WHITNEY, 1988, apud MUNIZ JR., 2010). However, mortality, since the basic idea until it becomes a profitable product can go up to 95% (HOLLINS and PUGH, 1990).

In the automotive industry, a strong economic chain with multiple effects on the economic and social tissues (STURGEON, VAN BIESEBROECK, and GEREFFI, 2008; CENTER FOR AUTOMOTIVE RESEARCH, 2010; ILI, ALBERS and MILLER, 2010; FERREIRA FILHO et al., 2013) those figures are huge: as an example, back in the 1985-1990 years, one single day delay in the automotive industry had an estimated cost of US$ 1M in lost profits. Therefore, companies that are able to launch their products four or five months faster than the competitors have a potential incremental profit of hundreds of million dollars (CUSUMANO and NOKEABA, 1990).

In Brazil, where automotive industry has grown from an import substitution model (LATINI, 2007) to become one of the largest producers and technology developers in this area, customization requirements for truck and buses (commercial vehicles) are even more critical, due to specific customers’ demands, generating an effort to develop innovative customer-oriented products: tailor-made vehicles is a revolutionary concept that has surprised, pleased, generated demand, stimulated new segments, leading to unprecedented occupation of niches (MAN).

For this reason, the field survey has been performed at a commercial vehicle manufacturing plant installed in the southern Rio de Janeiro state, Brazil. With approximately 4,500 people and a production capacity over 300 units per day, the unit comprises the World Trucks and Buses Development Centre, a space for research and creation of new models and development of new technology-embedded products. The choice of such unit for the field survey is also justified by its relevance, as subject of study by several authors (COLLINS and BECHLER, 1997; DORAN; HILL, 2009; SALERNO, CAMARGO, and LEMOS, 2008; IBUSUKI, KOBAYASHI, and KAMINSKI, 2012), due to its Modular Consortium model, in which the partners interact directly on the final product assembly line, sharing physical space and responsibilities. Although such production system concept is quite relevant, it will not be discussed in this article.

3 PROCEDURES AND TECHNIQUES

The methodology used to carry out the present qualitative research has gone through the five steps listed below, along a five-month period:

- ✓ Firstly, the review and analysis of the existing literature, covering the conceptual basis of mass customization and SBCE;
- ✓ Secondly, the identification of researchers, professors and technicians (or teams) involved in PDP research and support, especially in the automotive industrial condominium in southern Rio de Janeiro state, Brazil;

- ✓ Thirdly, non-structured interviews with Technical and Administrative managers involved to PDP/NPD were performed. A total of eight managers were interviewed, i.e.: Design Chief Engineer; Product Concept Manager; Integration/Complete Vehicle Test Manager; Project Tracking Manager; Powertrain Engineering Manager; Structural and Chassis Engineering Manager; Body and Trim Manager; and Electric/Electronic Engineering Manager.
- ✓ Fourthly, attending to PDP technical meetings, at the studied company; and
- ✓ Finally, consolidation of interview/research findings.

4 THEORETICAL FRAMEWORK

The concepts of mass customization and Lean PDP/SBCE are discussed in this topic, while some related literature is also referenced.

4.1 MASS CUSTOMIZATION

Pine II (1992) proposed a framework to analyze an environment of rapid change and competitiveness with difficult predictability, no longer supported by traditional forms of business management and mass production. The model is based on company product and process status: as shown in Figure 1, the intersection between stable and dynamic dimensions results in four categories of productive organization: invention, continuous improvement, mass production, and mass customization.

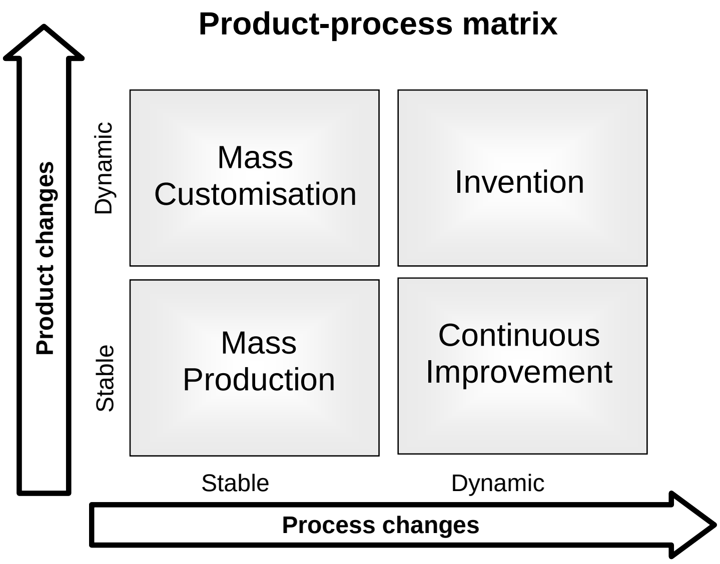

Figure 1: Product-process matrix (PINE II, 1992)

There are two broad categories of change in the matrix (BOYTON, VICTOR, and PINE II, 1993, p.42):

- ✓ Product change involves the demands for new products or services. The changes firms face in their markets because of competitor moves, shifting customer preferences, or entering new geographical or national markets are categorized as product changes; and

- ✓ Process change involves the procedures and technologies used to produce or deliver products or services. The term "process" refers broadly to all the organizational capabilities resulting from people, systems, technologies, and procedures that are used to develop, produce, market, and deliver products or services.

These two types of change can be either stable or dynamic. Stable change is slow, evolutionary, and generally predictable. Dynamic change is rapid, revolutionary, and generally unpredictable (BOYTON, VICTOR, and PINE II, 1993, p.42).

Although the categories are not precise and their boundaries are not easy to identify, the model has been proven useful as a reference in strategy definition, since, nowadays, demand and competition conditions are not limited to the high-low volume dichotomy. According to Boyton, Victor, and Pine II (1993), the model helps managers to: (1) assess their competitive position by understanding where their firms have been in the past; (2) build a vision of where their firms must be in the future; and (3) create a transformation strategy to turn that vision into reality.

The quadrant "Invention", an intersection of dynamic products and dynamic processes, also known as job-shop design, indicates companies dependent on constant innovations, which rely on highly skilled human resources, capable of exploring new ideas, rarely committed to production cost issues. These organizations often are separate research and development units within mass-production organizations (BOYTON, VICTOR, and PINE II, 1993), in which high costs of process innovation are supported by profits from mass production activities or continuous improvement.

In some markets, the nature of product demand is still relatively mature, stable, large, and homogeneous. That does not mean efficiency drives to stability and avoiding change. In the quadrant "Continuous Improvement", based on dynamic processes and stable products, refers to companies pursuing the main goals of fastness and inexpensive improvement of operational performance and management processes. Teams are intensive forums through which process change is pursued and implemented, in an ongoing sequence of Kaizen-type actions.

The quadrant "Mass Production" is related to companies that compete under conditions of stable product and stable process change: product specifications and demand are relatively stable and predictable. Companies' competitive advantage and profitability is based on standardized production cost reduction and efficiency of capital and manpower, so, maximum efficiency is achieved by dedicating the capital and human assets of the firm to the production of standardized goods or services. Thus a mass production organization is intended to respond to and initiate as little change as possible (BOYTON, VICTOR, and PINE II, 1993).

In the studied company, parts of its activities are related to this quadrant: a portfolio of out-of-the-shelf products is regularly produced and commercialized through dealers. High volume of standard products gives the tone to the Production system, in a "Fordism" style.

Finally, the quadrant "Mass Customization", one finds a scenario of dynamic product change and stable process change. It happens because/when customers increasingly make unique and unpredictable product demands. Boyton, Victor, and Pine II (1993) indicate that, as new competitors arrive and customer preferences change, predicting customer demand and articulating product specifications becomes more difficult than ever, but those changes evolve into recognizable patterns, allowing the organization to build stable but flexible platforms of process capabilities or know-how over time. As a result, organizations increase process efficiencies in clearly conditions of stable process change.

Therefore, the major distinguishing characteristic of the mass-customization design is its capacity to produce product variety rapidly and inexpensively, in direct contradiction of the assumption that cost and variety are tradeoffs, mass customizers organize for efficient flexibility (BOYTON, VICTOR, and PINE II, 1993), i.e., refers to fast, low cost, and varied production companies, fulfilling a large proportion of consumers through a large variety of products and innovations.

Spahi and Hosni (2009) determined the optimal degree of customization from a product structural design perspective, based on the concept of the so-called “Magnitude of Customization” (MOC), a unit to measure the degree of customization for products based on quantifying the extent of options per module or the extent of customizable features per component for a product in a mass customization system, establishing an optimal solution to how far an organization should customize a product to best satisfy its own organizational strategic goals.

Mass customization has been studied by several authors (MACCARTHY and BRABAZON, 2003; QUINTELLA and OLIVEIRA, 2007; MACHADO and MORAES, 2008; PINTO, GUTIERREZ, and QUINTELLA, 2010; FOGLIATTO, SILVEIRA, and BORENSTEIN, 2012; POURABDOLLAHIAN et al., 2013; SHAO, 2013), and it has the potential to help companies increase revenue and gain competitive advantage, improve cash flow, and reduce waste through on-demand production.

Profitable mass customization of products and services, according to Ganghi, Magar, and Roberts (2014), requires success in two broad areas: (i) identifying opportunities for customization that create value for the customer and are supported by smooth, swift, and inexpensive transactions for both consumers and producers; and (ii) achieving a manageable cost structure and cost level for the producer even as manufacturing complexity increases.

Mass customization offers up taxonomy of customization/modularity to answer customer requirements, and can generate valuable data that may be used in the development of standard products and in online marketing and public-relations campaigns. Ganghi, Magar, and Roberts (2014) identified two groups of technologies that enable mass customization, make it more practical today, and will drive further advances in the near future:

- ✓ Those that make it easier to create customization value for the consumer - Social media and crowdsourcing, allowing customers to create real and virtual products; Online interactive product configurators; 3-D scanning and modeling, giving consumers the ability to scan themselves, upload the models, and start ordering “tailor-made” products; e-commerce recommendation engines, helping customers configure products just for them; and smart algorithms and better data-processing capacity to enable dynamic pricing, thereby reducing the time consumers have to wait; and
- ✓ Those that control costs for the producer, despite the challenges of manufacturing complexity - Enterprise and production software; and Flexible manufacturing systems, essential to making small-batch production for mass customization profitable.

Unlike the mass producer, the mass customizer organizes labor to work effectively in a dynamic network of relationships, and to respond to work requirements as defined by customer needs (BOYTON, VICTOR, and PINE II, 1993). But it requires PDP flexibility, speed and robustness.

This is a major challenge for the company studied in this paper, since, besides the high volume-high standardization activities (i.e.: mass production quadrant), the Special Vehicle Engineering Group has to deal with on-demand vehicle projects. Each order is usually unique (customized), requiring the development of vehicle projects, which will be manufactured in very low quantities (sometimes, one single unit). Depending on customer needs, it might require unique chassis design, specific powertrain, hydraulic systems, controls, injection system, brake system, fuel tank, harness, suspension, etc. Due to a great demand for such customized vehicles, the company faces the following scenario: many low-quantity batches of customized products are manufactured, making an overall high-quantity production of non-standard (i.e.: customized) products. That fits into the description of the mass customization quadrant.

As so, the studied company deals with two quadrants at same time: mass production, for standard/regular products, and mass customization for customized vehicles. In this research, just the late one will be discussed.

4.2 SET-BASED CONCURRENT ENGINEERING

Morgan and Liker (2006) emphasize the PDP front-loading effort, taking advantage of initial flexibility/freedom to change, to fully exploit alternative solutions. The SBCE is the core enabler of the Toyota’s Lean Product Development (AL-ASHAAB et al., 2013): concept proposals are retained further into the process, deliberately delaying some decisions, so that design is kept open, emphasizing the parallel development of acceptable design solutions at the intersection of product capability, process and solution alternatives (MORGAN and LIKER, 2006; ROZENFELD et al., 2006).

Such strategy has the advantage to not lock up at a specific solution in a too early stage, since a lot can happen during the project lifetime that can change conditions drastically (COOPER, 2007; BONABEAU, BODICK, and ARMSTRONG, 2008), and rework that occurs late in the product life cycle is dramatically more expensive than design work performed early in the cycle (KENNEDY, SOBEK II, and KENNEDY, 2013).

Costa and Sobek II (2003), Rekuc et al. (2006), Eisto et al. (2010), and Khan et al. (2013), describe the SBCE rationale: broadly consider sets of concept alternatives first, and, as the product launch deadline approaches, the set of alternatives will be gradually narrowed, eliminating weaker solutions. Some decisions are purposely delayed, although what appears infeasible and/or too inferior is discarded, while what remains acceptable continues to be studied, overlapping development activities. Even incomplete information is passed on to suppliers. The end result, as possibilities converge, will not be subject to change: the solution is final. It contrasts to the traditional design practice, which funnels the decisions, closing possibilities as quick as possible, by determining the approximate design solution early in the project. Qureshi (2011) labels such kind of project decision process as “point-based design”, in opposition of the “set-based design”.

The concept of considering a broader set of alternatives earlier and delaying certain decisions seems counterintuitive (LIKER and MORGAN, 2006), but it purposes to prevent prematurely getting rid of good ideas, so that development risks are reduced, along with reworks and development time. Kennedy (2003), Maksimovic et al. (2011), and Saad et al. (2013) explain that the risk reduction on SBCE occurs due to redundancy, robustness, and knowledge absorption. Indeed, a shift from developing a single-point design to developing a set of possible designs have proven effective at reducing development rework (KENNEDY, SOBEK II, and KENNEDY, 2013).

Sobek II, Ward, and Liker (1999) described three main principles of SBCE, as follows:

- ✓ Map the design space - achieve a thorough understanding of the set of design possibilities, also known as the design space;
- ✓ Integrate by intersection - ensure that design teams integrate sub-systems by identifying solutions that are workable for all functional groups; and
- ✓ Establish feasibility before commitment - narrow sets down to an optimum solution at the system level.

The multiple concept approach in product development is not new: Krishnan and Bhattacharya (2002) discussed the development of products in the technological uncertainty environment, deciding whether using a robust and proven technology or choosing a technology still uncertain, but capable to leverage competitive product. Through the use of stochastic formulas, the authors developed models to establish the optimum technology innovation level, balancing risk involved with expected value generated, based on the following variables: margins expected by the use of new technology, development delay impact, expected demand, cost and total time expected. Such study has evaluated the redundancy in development (proven technology and new technology), weighing the extra cost compared with its expected gains. Stochastic models for PDP enhancement have also been used by Bhuiyan, Gerwin, and Thomson (2004), Kleyner (2005), and Lee and Suh (2008).

The implementation of the lean thinking in all business processes is a promising approach (DOMBROWSKI, ZAHN, and SCHULZE, 2011). Some researches demonstrate that the SBCE is in evolution, as shown in the following examples: Nahm and Ishikawa (2005a; 2005b) proposed a design methodology to be used with SBCE which integrates meta-modeling techniques, modified fuzzy arithmetic, design of experiments, robust design techniques, and uncertainty analysis. Inoue, Nahm, and Ishikawa (2013) proposed a design approach that obtains a ranged set of feasible design solutions while incorporating the designer's preference for design parameters. Schäfer and Sorensen (2010) provided a general valuation model for the optimal design of the PDP, exemplified by automobile development. Based on the case studies and literature on the role of organizational capabilities in creating value for the organization, a numerical example demonstrates that under certain circumstances, developing multiple design alternatives in parallel is shown to generate significant value, fully accounting for the increase in costs of doing so. Ford and Sobek II (2005) adapted real options concepts to product development management to explain the Toyota’s fastest development time versus intentionally delaying alternative selection paradox.

Sobek II, Ward, and Liker (1999), however, indicate as a disadvantage of the SBCE that it requires a lot of the people who setup the so-called solution areas, what is a concern, based on Baxter (1995) concept that there must be a compromise between the factors that add value to the product and those that cause cost increase.

However, Rocha, Delamaro, and Affonso (2011) refute such idea: the authors have developed a theoretical model of PDP gain through the use of multiple-concept, comparing the additional manpower required to develop more than one concept at the time versus the project reliability increment (thus design rework reduction). The authors inferred that such trade-off would worthwhile, i.e., the gain is so high in terms of design reliability that it is expected that the development team would, in fact, work less when multiple concepts are developed, due to design looping/rework reduction. Indeed, in a real project analyzed, with twelve new concepts to be developed to customize the existing 25 Ton 6 x 2 vehicle platform to specific requirements, a "gain per unit of creation and development effort" (as labeled by the authors) of 28.34 was calculated, showing how advantageous is the use of multiple concepts on automotive PDP.

Rocha, Oliveira, and Affonso (2012) performed a SBCE gain sensitivity analysis. The findings indicated that even though the use of multiple concepts can be advantageous, the decision about quantity of concept developed simultaneously affects the potential development gains. Based on the study, simple projects might not get enough advantage by SBCE use. The same happens with the quality of the ideas generated by the development team, i.e.: the lower is the project idea success-rate, the higher is the potential project gain by developing multiple concepts. As concluded by the authors, the SBCE provides great development advantages when used in mid-high complexity projects. Therefore, simple follow-on products and “facelifts” may better use traditional one-hit design practice (a.k.a. point-based design), since an elevated amount of workload to develop multiple concepts would impact negatively the overall development performance, mainly if the development team is quite competent and capable.

5 THE USE OF SBCE ON PDP

This Section presents the research findings obtained through the interviews and some reflections from this interactive process, based on a cross-referenced literature. Similar opinions and managers’ perceptions have been consolidated, due to space restrictions, although, not jeopardizing the overall information-sharing goal purported in this paper.

In the interview with the Product Concept Manager, is has been said that the Toyota’s Lean PDP is followed and, therefore, the Concept Design Team is oriented to develop three concepts (three ideas) for each feature, mechanism or project subsystem. Although, barriers are to be overcome in a daily basis to keep on this routine, since designers, design engineers, and other technical people involved to PDP/NPD have a tendency to diminish the value-added to “do the same thing more than once”, having the perception of a time-wasting practice. As related by the Manager, barriers get even tougher as project deadlines get closer, due to the perception that, since the time is short, people involved to the activities have “no time to waste”.

Such approach is quite dangerous, since it encompasses an optimist attitude (wishful thinking), i.e., the assumption that ideas being pursued will work properly and, therefore, there is no reason to develop alternative ideas/concepts. On the contrary, if one single idea fails, the whole project will suffer the impact: solutions to the failure are to be provided, which includes brainstorming it, validating ideas, preselect some of them and prioritize development, allocate additional resources to do so, have them tested, etc. Indeed, a reactive attitude like that leads the company to the worst scenario, since it is toughest moment to come up with ideas and problem solutions, due to the time pressure. Had other ideas been previously developed (i.e.: in parallel), they would be available to catch up, providing solutions "ready to go" in no time.

The development of multiple design concepts generates another gain, as highlighted by the manager: there is a natural process of idea enhancement/improvement, like an ideas' learning curve, where concepts are refined and matured, as if there were a PDCA cycle involved. Such concept is found implicit in the controlled convergence model, developed by Pugh (1991), in which different concepts are generated, compared, and lead the rise of additional concepts, while weaker concepts are eliminated.

Some of the excuses presented are related to "too much work to be done", mainly because of the amount of different projects that must be developed simultaneously, i.e., the multiplicity of customized products required by customers in the mass customization environment. It is a concern to the manager, since it can become a "snowball", because project failures happen and, the more project the design people is involved on, the more failures are to be fixed somehow. That is the situation the Concept manager is fighting against, insisting on the SBCE use by his team.

In regards to this situation, that lack of institutionalized procedures might be understood as a lack of work process maturity: it seems that even though the concepts of SBCE are clear to the manager and the advantageous use of it, he has to rely in his leadership to have people following the prescribed steps, i.e.; they seem to obey, but are not convinced of the real advantage to them and to the company. Any distraction and it seems people try to escape from the "additional" workload of developing multiple project concepts.

Interviews with other managers reinforced such perception: most of them respect the Concept manager attitude and have the tendency to agree with him in regards to the importance of the SBCE use. But, even though no disagreement is explicit in regarding to that, at same time, some managers understand that, "in the moments of crises", developing multiple concepts might not be adequate, due to the additional time consuming, what bring the discussion back to the start point. Also, as stated by one of the managers, benefits would show up just "occasionally", when a specific concept fails and it can be quickly replaced by another one, while, most of the times, concepts work just fine. It sounds like the SBCE is seen by some people as just a theory, a non-proved idea in real life. However, based in the literature and many case studies, SBCE has proven its validity as an enabler to increase project reliability and predictability, and, therefore, capable to reduce the overall development time and cost.

This is even more critical when dealing with on-demand projects in a mass customization environment: the demand to continuously develop projects that fulfill unique customer requirements puts a lot of pressure for successful projects. Therefore, using methods and procedures to increase the project reliability, reduce reworks/design loopings, and, at the end, reduce the overall development time, bring strategic advantage to the companies. The SBCE, for sure, is one of the key enablers to such scenario, but cultural barriers are to be broken down until it gets full acceptance by PDP teams.

6 CONCLUSIONS AND REMARKS

This paper explored the concept of the SBCE in the PDP for automotive projects, enabling the company to the mass customization. Unlike the PDP practices commonly used, in which one seeks to identify as early as possible the design concepts, so that they can be frozen, usually as a project maturity metric, this paper asserts that the development of multiple concepts and consequential decision delay leads to considerable project development gains, substantially increasing the chance of success and allowing time and cost reductions.

The automotive industry is on the verge of technological changes that will enable the full entry into the world of mass customization (ALFORD, SACKETT, and NELDER, 2000). The hypothesis that the SBCE is an enabler to such change has been analyzed under the lens of the existing literature and interviews in a commercial vehicles' Plant/Design Center. Theoretical and practical conclusions are as follows.

Traditional project development wisdom dictates the early selection of a single design in order to freeze interfaces between product subsystems, so that team members can work effectively in parallel – concurrent engineering -, resulting in more productive product development efforts. However, Toyota Motor Corporation achieved the fastest development times in its industry by intentionally delaying alternative selection, through the use of the strategy termed set-based development (FORD and SOBEK II, 2005). Many other empirical studies corroborate with such findings and testify to the validity and efficiency of the SBCE.

At the studied company, even though the SBCE is part of daily product development activities, due to what seems to be caused by lack of understanding/knowledge of the whole process, environment to support processes is not stable/mature and people has a tendency to run away/skip the multiple-concept development. Due to the enormous demand to develop unique projects, under the mass customization strategy, recommendations are to have development team trained into the SBCE theoretical fundamental and evidences of gains and successful cases are reported, so that the adoption of the practices are not just imposed, but people use it because they believe in the advantages over traditional point-based PDP.

The paper findings may be used by any organization that seeks to maximize returns on investments in new product development, fulfilling customer needs faster and more reliably, depending on mass customization implementation, maintenance, and improvement. However, further research must be conducted, raising historical success data by the use of SBCE, comparing project performance with other projects developed through conventional PDP. It is also recommended to investigate the cost-benefit analysis regarding the effect over product time-to-market.

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