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Mass Customization Enablement Through Lean Design & Set-Based Concurrent Engineering Application

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ABSTRACT: This research, which is an expanded version of a paper presented at the XVII SIMPOI - Symposium of Production Management, Logistics and International Operations, 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 imposed unprecedented pressure over companies, coining new challenges to them in a fierce competition environment (Scala, Purdy, & Safayeni, 2006). Demands for better quality, lower cost, technological product updating (Zacharia & Mentzer, 2007), growing consumer demand for quick responses, smaller production batches of customized products, shorter product lifecycles, customers' new requirements (Lam & Chin, 2005), multiple regulatory changes and the constant pressure for innovation obligates companies to continuously develop and offer products and services that must be perceived by customers as value-adding opportunities. By creating customer-producer links, companies can prevent competitors from getting part their market share (Alvan & Aydin, 2009, Rocha, Delamaro, & Affonso, 2012). It makes the product development process (PDP) a critical success factor for companies (Rocha & Delamaro, 2012).

In mutable environments, with high levels of uncertainty, the constant possibility of flexibility results in better design and products developed (MacCormack, Verganti, & Iansiti, 2001). 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 of them will be profitable.

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). However, mortality, since the basic idea until it becomes a profitable product can go up to 95% (Hollins & Pugh, 1990).

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).

In the automotive industry, a strong economic chain with multiple effects on the economic, technological, and social tissues (Center for Automotive Research, 2010, Ili, Albers, & Miller, 2010, Ferreira Filho, Olivares, & Rocha, 2013, Rocha, Souza, Nascimento, & Oliveira, 2014, Sturgeon, Van Biesebroeck, & Gereffi, 2008), figures are gigantic: 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. Companies that were able to launch their products four or five months faster than the competitors have a potential incremental profit of hundreds of millions of dollars (Cusumano & Nokeaba, 1990).

Therefore, companies face the challenge to make their PDP flexible, efficient and effective to ensure their 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 & Delamaro, 2007). So, the "do-it-right-the-first-time" approach seems to be a company survival rule. But, along the development process, internal and external factors interact, causing a high complexity scenario. 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 and mainly in a time of crisis, avoiding the tendency to overcommit, abandon processes, and, consequently, being unable to achieve and/or repeat their successes (Rocha, Quintella, & 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, Smith, Jiao, & Chu, 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, Ward, Milligan, & Berry, 2000, p.605).

Three statements are considered to build the rationale in this article: (i) 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; (ii) Al-Ashaab et al. (2013a) indicate the Set-based Concurrent Engineering (SBCE) as a key element in the Lean PDP model; and (iii) Lean systems are strongly dependent on people acceptance and involvement (Morgan & Liker, 2006, Holweg, 2007), and, therefore, "To turn the employees towards participation a new way of thinking is needed" (Naveen, Sunil, Sanjay, & Abid, 2013, p.4), but, to do so, companies must overcome numerous obstacles (Karlsson & Ahlström, 1996, Crute, Ward, Brown, and Graves, 2006).

The present study focuses on understanding how SBCE can contribute to the implementation of mass customization and discuss the barriers to its successful implementation within the organization. To this end, we performed a case study in a commercial vehicle manufacturing plant installed in the southern Rio de Janeiro state, Brazil.

The next paper sections are as follows: Section "Literature Review" comprises the fundamentals of Mass Customization and Lean PDP/SBCE, presenting, also, a brief literature review of those themes; Section "Procedures and Techniques" presents the research methodology; 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, as well as the barriers identified to do so. Finally, at the Section "Conclusions and Remarks", findings are assessed and discussed, while proposals for additional researches are made.

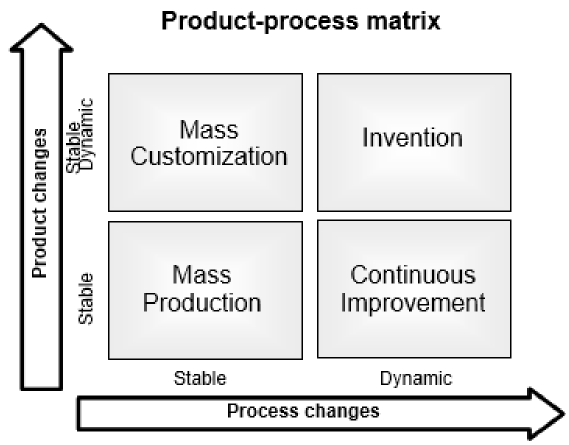
2 LITERATURE REVIEW

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

2.1 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, & Pine II, 1993, p.42), which can be either stable or dynamic:

- 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;
- 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;
- Stable change is slow, evolutionary, and generally predictable; and
- Dynamic change is rapid, revolutionary, and generally unpredictable.

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 the authors, upon the company quadrant identification, 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 "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.

In some markets, the nature of product demand is still relatively mature, stable, large, and homogeneous. But it does not mean efficiency drives to stability and avoiding change. 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 "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, in which high costs of process innovation are supported by profits from mass production activities or continuous improvement.

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: 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 et al., 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.

Mass customization has been studied by several authors (Fogliatto, Silveira, & Borenstein, 2012, MacCarthy & Brabazon, 2003, Machado & Moraes, 2008, Pinto, Gutierrez, & Quintella, 2010, Pourabdollahian, Corti, Galbusera, & Silva, 2013; Quintella & Oliveira, 2007; 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.

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, & Roberts, 2014).

Profitable mass customization of products and services, according to the authors, 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 et al. (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 et al., 1993), requiring PDP flexibility, speed and robustness. Such approach has been studied by Spahi and Hosni (2009), who 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.

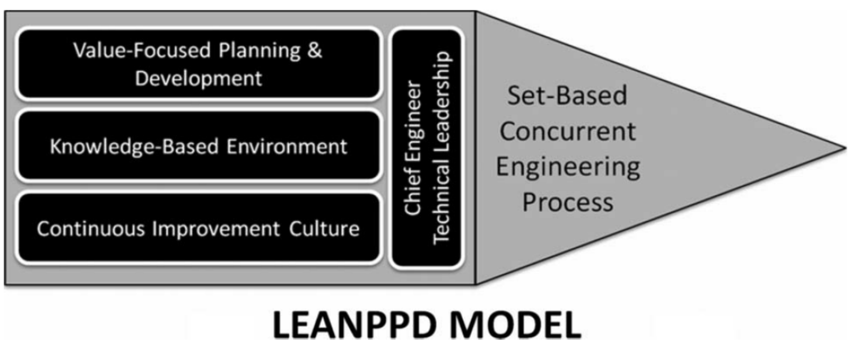
2.2 Set-Based Concurrent Engineering

The Construction Industry Institute (2012) defines front-end loading as the process of developing sufficient strategic information with which owners can address risk and make decisions to commit resources in order to maximize the potential for a successful project. Baxter (1995) emphasizes the PDP front-end loading effort, taking advantage of initial flexibility/freedom to change, to fully exploit alternative solutions, while Morgan and Liker (2006) describe the PDP front-loading as one of the Lean PDP principles. In regards to NPD, the freedom to explore different concepts at low expense commitment and low financial impact at beginning of the development makes the SBCE an important tool to companies' winning PDP strategy.

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 & Sobek II, 2005). Many other empirical studies corroborate with such findings and testify to the validity and efficiency of the SBCE.

The SBCE is one of the core enablers of the Toyota's Lean Product Development (Al-Ashaab et al., 2013b, Khan 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 & Liker, 2006, Rozenfeld et al., 2006). A conceptual Lean PDP is seen in the Figure 2.

Figure 2: Conceptual lean PDP (Khan et al., 2013)



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 (Bonabeau, Bodick, & Armstrong, 2008, Cooper, 2007), 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, & Kennedy, 2014).

Costa and Sobek II (2003), Morgan & Liker (2006), Eisto, Hölttä, Mahlamäki, Kollanus, and Nieminen (2010), Khan et al. (2013), and Rekuc et al. (2006), 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 & 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, Al-Ashaab, Shehab, & Sulowski (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 has proven effective at reducing development rework (Kennedy et al., 2014).

Sobek II, Ward, and Liker (1999) described the 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, & Schulze, 2011). Some researches demonstrate that the SBCE is in evolution, as 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.

Intriguingly, Baines, Lightfoot, Williams, and Greenough (2006) claims that Toyota's Lean manufactur-

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ing system is actually an extension of their product development philosophy and not the reverse, but most western manufacturers are focusing their Lean initiatives at operations with few attempts to adopt Lean in design-related activities.

Sobek II et al. (1999), however, indicate as a disadvantage of the SBCE that it requires a lot of the people who setup the so-called solution areas, which conflicts with 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, Allen, Liker, Cristiano, and Sobek II (1995) highlighted that the Toyota's development process requires fewer people than other companies.

Rocha, Delamaro, and Affonso (2011) refute such disadvantage: 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 gains are so substantial 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.

> *The authors assert that if the odds of developing a winner project concept were 90%, a product project requiring 50 new concepts would have a 0.5% 'do-it-right-the-first-time' success rate (0.950 = 0.5145%), whereas, developing three concept simultaneously (for each concept area, i.e. each of the 50 product areas requiring the development of a new concept), the affected project area would fail only if the tree concepts fail, what would represent a 0.1% situation (0.13 = 0.1%). Therefore, since the odds of each successful concept area would be, now, 99.9%, the overall expected success rate would be above 95% (0.99950 = 95.1206%) (Rocha, Affonso, & Oliveira, 2013).*

Indeed, in a real project analyzed, with twelve new concepts to be developed in order 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, Affonso, and Oliveira (2012, 2013) performed a SBCE gain sensitivity analysis, considering the following variables:

Ta: Average concept (idea) success rate;

c: Quantity of different concepts for each design area; and

n: Quantity of design areas (areas requiring the development of new concepts).

The authors performed a 5,000-run simulation, adopting the following limits: *Ta* to be between 20% and 90%, since values out of those limits would be quite improbable; *c*, between 2 and 10, justified by the fact that there must be at least two different concepts (ideas) for each area, while ten seem to be too much; and *n* to be between 2 and 30, based on the project complexity level ranges for automotive industry, i.e., 2 to 4: low complexity; 10 to 20, medium; and, 20 to 60, high (Rocha, Delamaro, & Affonso, 2011).

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.

Reinertsen (2009) defends that there is an optimum number of parallel development of multiple solutions, which occurs when incremental value added by each additional solution, in terms of risk reduction, equals the incremental development expense added by it.

As seen along the previous paragraphs, many studies focused on understanding the efficiency of the SBCE. Hence, as management researches aim to improve the relationship between theory and practice (Tranfield & Starkey, 2002), i.e.: the relevance and the application of findings, a fundamental concern lies with its implementation process, a subject that seems to be overlooked by researchers, since this study shows that very few of them have discussed the implementation of the SBCE. Thus, the present research purposes to contribute to the literature by highlighting, through a case study, difficulties and barriers found on SBCE full adoption in a Truck/Bus Development Centre.

3 PROCEDURES AND TECHNIQUES

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 critical, due to the specific customers' demands for specific applications: in this industry, examples such as mining, beverage delivering, garbage and recycling collection service, etc., require unique product configuration and design features development. Such market-approach strategy generates and demands an effort to develop innovative customer-oriented products: tailor-made vehicles, as perceived in this industry, is a revolutionary concept that has surprised, pleased, generated demand, stimulated new segments, leading to unprecedented market niches' occupation (MAN).

Due to the importance of the automotive industry and the specific characteristics and dynamics of commercial vehicle development, a case study has been performed at a commercial vehicle manufacturing plant installed in the southern Rio de Janeiro state, Brazil. The case study methodology, defined by Gerring (2004, p.341) as "an intensive study of a single unit with an aim to generalize across a larger set of units", has been adopted with the intent to investigate the SBCE phenomenon within its own context (Yin, 2005), i.e.: its application in the plant unit, exploring related processes in detail, through data gathering from multiple sources, in order to strengths the theory by triangulation of the evidence (Eisenhardt, 1989).

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 practical and academic relevance, as subject of study by several authors, as well as a industrial operations' benchmark (Collins & Bechler, 1997; Doran & Hill, 2009; Ibusuki, Kobayashi, & Kaminski, 2012, Salerno, Camargo, & Lemos, 2008), due to its Modular Consortium model, in which the partners interact directly on the final product assembly line, sharing physical space and responsibilities.

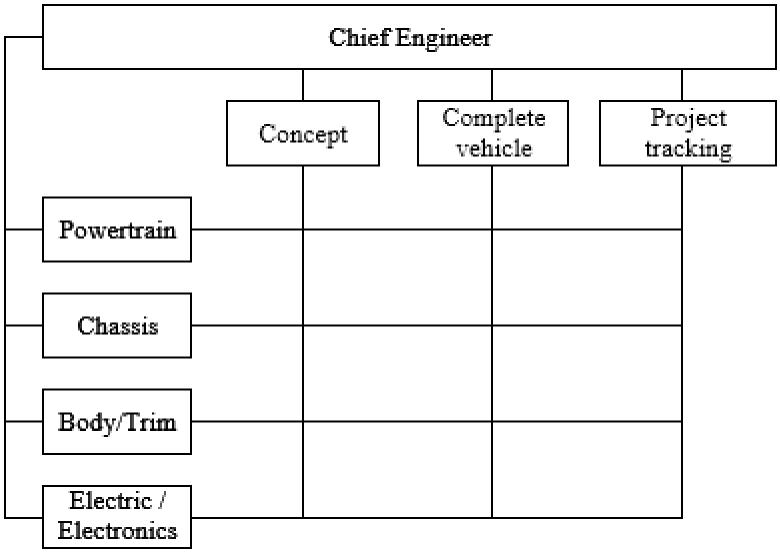
In regards to the product-process matrix (described in 4.1), the studied company activities are related to two quadrants: a portfolio of out-of-the-shelf products is regularly produced and commercialized through dealers, so, high volume of standard products gives the tone to the Production system, in a "Fordism" style (mass production quadrant). But its major challenge relies in the Special Vehicle Development Engineering, i.e., 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, what fits into the description of the mass customization quadrant, focus of the present research.

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, encompassing the conceptual basis of mass customization and SBCE;
- Secondly, the research planning and agreements, i.e., data collection processes; identification of key players and/or people to be interviewed, in essence, people directly involved in PDP research and support; case study proposal submission, negotiation and approval; data analysis and results screening, etc.

Even though the boundaries among companies within the Modular Consortium are, sometimes, inaccurate, PDP activities are under one single company responsibility, through its World Trucks and Buses Development Centre. Therefore, out of such company, eight managers have been identified to be interviewed, as agreed with the Design Chief Engineer (the first interviewed): Product Concept Manager; Integration/Complete Vehicle Test Manager; Project Tracking Manager; Powertrain Engineering Manager; Structural and Chassis Engineering Manager; Body and Trim Engineering Manager; and Electric/Electronic Engineering Manager. Such small but representative sample encompass all key decision-makers involved in the PDP, as seen in the Figure 3.

Figure 3: World Trucks and Buses Development Centre matrix structure



- Thirdly, we performed semi-structured interviews with the selected managers involved to PDP/NPD, having the following questions as an interview basis:
  1. Do you know the concept of set-based concurrent engineering, i.e., the parallel development of multiple design concepts? Select: (yes) or (no);
  2. Do you use it? Select: (a) always; (b) sometimes; (c) once in a while; or (d) never;
  3. Why? Select: (a) You are told to do so; (b) You are suggested to do so; (c) It helps achieving PD objectives; or (d) other: ______________________ (if response to question 2 was "never");
  4. Is it a good practice (advantageous)? Why? (open question);
- Fourthly, we attended to four PDP technical meetings, at the studied company. Attending to those meetings was an opportunity to collect data from different sources, e.g. reports, drawings, test results, opinion from different managerial and technical people, lesson-learned discussions, with the intent to identify the SBCE use: whether regular, occasional, or even scarce/unused; and
- Finally, consolidation of interview/research findings. Interviews could not be recorded: as previously agreed, written notes were taken for future compilation and analysis. Data collected from interviews was cross-checked and, also, compared with findings from documental analysis (drawings, reports, etc.). Eventual inconsistencies have been forwarded to the managers for further clarification. A final version of the research has been submitted to the Engineering group prior to submission, in order to assure that only work processes and people perceptions would be made available and product details and classified information would not be disclosed by the paper publication.

4 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 observation, documental and literature cross-checking. Similar opinions and managers' perceptions have been consolidated, due to space restrictions, although, not jeopardizing the overall information-sharing goal purported in this paper.

As identified along the interview reports compilation, all managers do know the concept of SBCE (question 1), but three responded "once in a while" and four, "never", in question 2. The reason for such response profile was explained by them in the question 3: only the Product Concept Group regularly develops multiple design concepts: other areas get involved into the development just after the concept basis has been established (even though all PD groups interact among them and have early involvement with the Concept group). Therefore, SBCE is used by other groups only when further detailing and/or virtual or real prototypes and tests are required, a situation usually pushed by the Product Concept manager.

Based on such findings, we compiled the responses in two groups: responses from the Product Concept manager, due to its relevancy, and from the other managers.

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. 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. Similar problem was identified by Kovacheva (2010):

> *People are resistant to changes on their working place even if the management is dedicated enough efforts in training programs and explaining the values of the new practice. Especially when workers veterans encounter the new challenge of changing their way of working and when they need to be convinced in the benefits of the new technique (p.37).*

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 (concepts) will work properly and, therefore, there is no reason to develop alternative ideas/concepts. The shortfall in this approach is that if one single idea fails, the whole project will suffer the impact: solutions to the failure are to be provided, which requires brainstorming, 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 difficulties such as having to develop ideas and solutions under 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: a process of idea enhancement/improvement, in a learning curve type of process, 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 they lead the rise of additional concepts, while weaker concepts are eliminated: an interactive process of getting rid, combining, and adding ideas and solutions to the set of concepts under consideration.

Although, the Product Concept Manager reported some people justifying for not use SBCE due 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. Such scenario is the one that the Concept manager is fighting against, insisting on the SBCE use even within his team: supervision seems to be required to prevent people to escape from the "additional" workload of developing multiple project concepts.

Interviews with other managers reinforced such perception: all 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, 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.

It seems that even though the concepts of SBCE are clear to the Product Concept manager and the advantageous use of it, namely, a method to increase the project reliability, reduce reworks/design loopings, and, at the end, reduce the overall development time, and bring strategic advantage to the companies, he has to rely in his leadership to have people following the prescribed steps. Cultural barriers are to be broken down until SBCE gets full acceptance and adherence by PDP teams: they seem to be not convinced of the real advantage to them and to the company.

5 CONCLUSIONS AND REMARKS

This paper explored the concept of the SBCE in the PDP for automotive projects, enabling the company to the mass customization, but its full implementation faces barriers imposed by PDP technical and even managerial people.

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, & Nelder, 2000). The contribution of the SBCE to such change has been analyzed under the lens of the existing literature and a case study in a commercial vehicles' Plant/Design Center: interviews with managers directly involved in PDP activities, as well as documental analysis and observation were part of the research methodology. Theoretical and practical conclusions are as follows.

The major product development challenge faced by the studied company relies on the Special Vehicle, i.e., unique (customized) projects, manufactured in low-quantity batches, adding up in a high-quantity production of non-standard products, which can be described as mass customization, a challenge for many companies in regards to manufacturing, due to operation complexity (Fisher & Ittner, 1999, MacDuffie, Sethuraman, & Fischer, 1996).

In the studied company, such complexity extends and is increased since the early phases of PD, being a cause of managerial attention. Therefore, this research contributes to the literature by discussing the impact of the mass customization in project phases, prior to manufacturing concerns, but also by pointing the use of the SBCE as an enabler to deal with such complexity.

Another contribution comes from the findings that, even though the SBCE is part of daily product development activities at the studied company, due to what seems to be a lack of understanding/knowledge of the whole process, such processes are not stable/mature and people has a tendency to run away/skip the multiple-concept development. This phenomenon was described by Kotter (2007, p.102): "Until new behaviors are rooted in social norms and shared values, they are subject to degradation as soon as the pressure for change is removed".

As stated by Baines et al. (2006, p.1545), "A truly successful application of Lean requires organization-wide changes in systems practices and behavior". Due to the enormous demand to develop unique projects, under the mass customization strategy, recommendations to the company management are to have development team trained into the SBCE theoretical fundamental and evidences of gains and successful cases are reported, so that connections between behaviors and corporate success are perceived (Kotter, 2007), and the adoption of the practices are not just imposed, but people use it because they believe in the advantages over traditional point-based PDP.

Those 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, taking in consideration not only the potential benefits of SBCE use, but also limitation to its acceptance and institutionalization.

However, limitations to this research rely on the fact that data and analyzes have been performed in one single company. Therefore, further research must be conducted, in other companies and industries, in order to check mass customization strategy suitability, SBCE adequacy to mass customization, but also 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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