# PRODUCT DEVELOPMENT PROCESS MATURITY LEVERAGE THROUGH THE USE OF SET-BASED CONCURRENT ENGINEERING PROCESS

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*The increasing need to improve products and services quality, as well as customers' satisfaction, has intensified the use of methods and techniques for process failure mitigation/elimination. Competitiveness is based on continuously developping and offering products and services, preventing competitors from getting part of their market share. Developing new products, although, involves a lot of risk and uncertainty: the influence of complexity in determining new product development strategies requires effort from organizations that must rely on their processes, avoiding the tendency to overcommit, abandon established practices and processes, and, consequently, jeopardize the capability to advance towards excellence and success. Such robust positioning is usually known as 'maturity'. The present article discusses the principles of Maturity Models and how high levels of maturity can be achieved on product development through the use of the Set-Based Concurrent Engineering (SBCE) Process, a product design and development system that leverages the product development process (PDP) robustness and reliability: acceptable design solutions are developed simultaneously, postponing final concept decisions and overlapping development activities. It contrasts to the traditional design practice, which seeks to establish the design concepts as early as possible, and changes are made where appropriate for improvement until a satisfactory solution emerges, resulting in rework and cost and time impacts, with no convergence prediction possible. Based on a real project situation, the article explores a company practice of developing three concepts (three ideas) for each feature, mechanism or project subsystem. The research was performed at a commercial vehicle Development Centre installed in the southern Rio de Janeiro state, Brazil. Data collection, analysis, and simulation were performed along a seven-month period, while a new commercial vehicle concept was developed, with technical discussions and meetings with the Design Concept manager and members of the development team. A mathematical model compared the multiple-concept PDP reliability increment (thereby reducing design rework and loops) with the additional manpower required to develop more than one concept at a time. Research findings indicate that organizations benefit from SBCE use to increase PDP maturity level, maximizing returns on investments in new product development, fulfilling customer needs faster, more reliably, and a lower overall development cost.*

*Keywords: New Producr development, Product Development Process, Maturity Models, Set-based Concurrent Engineering*

# 1 Introduction

Over the last decades, industrial companies have been facing unprecedented challenges, such as market changes, worldwide fierce competition, growing demand of consumers for quick responses, smaller production batches of customized products with short lifecycles, customers' new requirements, and multiple regulatory changes (Scala et al., 2006). Competitiveness is, therefore, based on continuously developing and offering products and services recognized by customers as value-added possibilities, preventing competitors from getting part of their market share (Rocha et al., 2012b), being the product development process (PDP) a critical success factor for companies (Quintella et al., 2005; Rocha & Delamaro, 2012).

Developing new products, although, involves a lot of risk and uncertainty: out of ten ideas about new products, three will be developed, 1.3 will be launched, and only one will be profitable (Baxter, 1995; Duber-Smith & Black, 2012). Research performed in the 90's showed that only 45% of companies were able to keep production costs within the budget and only 49% launched their products on schedule: on average, products cost 13% above the budget and are released six months late (Baxter, 1995). So, the influence of complexity in determining new product development (NPD) strategies is a subject that requires effort from Design and Project managers (SPILL, 2012).

NPD decisions must be wisely made, no longer based on trial and error, because changes occur more quickly than the lessons can be learned (Rocha & Delamaro, 2007): "the quality of a system or product is highly influenced by the quality of the process used to develop and maintain it" (SEI, 2010). Therefore, organizations must rely on their processes even in a time of crisis, avoiding the tendency to overcommit, abandon their processes, and, consequently, being unable to repeat their successes. Such robust positioning is usually known as 'maturity'.

The present article discusses the principles of Maturity Models and how high levels of maturity can be achieved on PDP/NPD through the use of the Set-Based Concurrent Engineering (SBCE) Process, a product design and development system that acts as an enabler of a flexible, cost-effective, sustainable, and robust product development.

# 2 Background

The increasing need to improve products and services quality, as well as customers' satisfaction, has intensified the use of methods and techniques for process failure mitigation/elimination. Management initiatives are used by companies to survive into such mutable and complex environment: consolidation of quality management systems, process mapping, increasing rate of products and services customization, and lean manufacturing are some of them (Oliveira et al., 2012a, 2012b).

Maturity Models and Set-based Concurrent Engineering are, also, allies toward the search for excellence. They are briefly described ahead, providing the necessary foundation for discussing the use of SBCE in NPD/PDP.

## 2.1 Maturity Models

The concept of maturity level comes from the principle that the Quality is a never-ending cycle of process improvement, i.e., a final destination is continuously pursued but never achieved. Therefore, Quality could not be ranked in a binary mode such as achieved or not,

yes or no, zero or one, etc. Rather, the quality can (and must) be measured, so that levels to be overcome can be identified as targets, adherent to the concept of continuous improvement.
Based in that, Crosby (1979) conceptualized the Quality Management Maturity Grid (QMMG): an organizational/business matrix that shows different stages of maturity of the company's quality management against six different measurement categories (management understanding and attitude; quality organization status; problem handling; cost of quality as % of sales; quality improvement actions; and summary of quality company posture), and how well they are embedded in an organization culture, with respect to service or product quality management. The QMMG columns represent the five maturity levels through which an organization or business shall advance towards quality excellence. In the lowest stage of maturity (Uncertainty), the organization is inexperienced, quality management is a low priority and reactive, etc. Overcoming such stage (or level), as quality management matures, the next steps are achieved sequentially: 'Awakening', 'Enlightenment', 'Wisdom', and the highest level, 'Certainty'.
The QMMG principles were further extended and applied to software development at IBM (International Business Machines) and Software Engineering Institute - SEI (Radice, 1985; Humphrey, 1989; SEI, 2010), credited with being the basis for the Capability Maturity Model (CMM) development, a five-level maturity model (Figure 1).

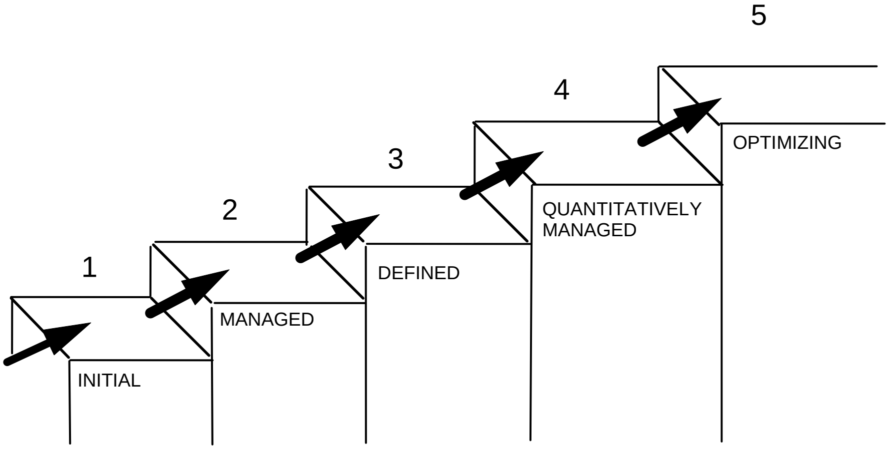


Figure 1: CMM Maturity Level Staged Representation. Source: SEI (1997)

Other maturity models have been developed over time: the PMMM - Project Management Maturity Model (Kerzner, 2010), OPM3 (Organizational Project Management Maturity-Model), developed by the Project Management Institute (2003), Systems Engineering Capability Model – SECM (EIA, 2002), Project FRAMEWORK, ESI International, Project Management Maturity Assessment Model, the Knapp & Moore Pty, the Maturity Model for PDP (Rozenfeld & Amaral, 2005), Prado-PMMM (Model Maturity in Project Management), etc. (Oliveira, 2006). All of them follow the same concept of continuous improvement. Later on, the CMMI (CMM Integration) was developed to sort out the problem of using multiple maturity models (SEI, 2010).
Goldenson and Gibson (2003) presented the results of the use of CMMI in various industries and organizations of all sizes in the United States, Europe and Australia (Accenture Consulting, Boeing, Bosch, General Motors, JP Morgan Chase, Lockheed Martin, Northrop Grumman, Sanchez Computers, Thales Air Traffic, Simulation & Training), with significant performance improvements in the areas of cost, timeliness, quality, customer satisfaction and return over investment.
The CMMI has five maturity levels (ML), each a layer in the foundation for ongoing process improvement, are designated by the numbers 1 through 5, as per SEI (2010):

#### 2.1.1 Maturity Level 1: Initial

Processes are usually ad hoc and chaotic. The organization usually does not provide a stable environment to support processes. Success in these organizations depends on the competence and heroics of the people in the organization and not on the use of proven processes. In spite of this chaos, organizations often produce products and services that work, but they frequently exceed the budget and schedule documented in their plans.

#### 2.1.2 Maturity Level 2: Managed

Projects have ensured that processes are planned and executed in accordance with policy; the projects employ skilled people who have adequate resources to produce controlled outputs; involve relevant stakeholders; are monitored, controlled, and reviewed; and are evaluated for adherence to their process descriptions. The process discipline helps to ensure that existing practices are retained during times of stress. The status of the work products are visible to management at defined points (e.g., at major milestones, at the completion of major tasks).
When these practices are in place, projects are performed and managed according to their documented plans. Commitments are established among relevant stakeholders and are revised as needed. Work products are appropriately controlled. The work products and services satisfy their specified process descriptions, standards, and procedures. The standards, process descriptions, and procedures can be quite different in each specific instance of the process.

#### 2.1.3 Maturity Level 3: Defined

Processes are well characterized and understood, and are described in standards, procedures, tools, and methods. The organization's set of standard processes is established and improved over time. These standard processes are used to establish consistency across the organization. Projects establish their defined processes by tailoring the organization's set of standard processes according to tailoring guidelines.
A defined process clearly states the purpose, inputs, entry criteria, activities, roles, measures, verification steps, outputs, and exit criteria. Processes are managed more proactively using an understanding of the interrelationships of process activities and detailed measures of the process, its work products, and its services.

#### 2.1.4 Maturity Level 4: Quantitatively Managed

The organization and projects establish quantitative objectives for quality and process performance and use them as criteria in managing projects. Process performance baselines and models can be used to help set quality and process performance objectives that help achieve business objectives. Quantitative objectives are based on the needs of the customer, end users, organization, and process implementers. Quality and process performance is understood in statistical and other quantitative techniques terms and is managed throughout the life of projects.
The organization and projects focus on understanding and controlling performance at the subprocess level and using the results to manage projects. For selected subprocesses, specific measures of process performance are collected and statistically analyzed, based on the understanding of the relationships between different subprocesses and their impact on achieving the objectives for quality and process performance. Predictions are based, in part, on a statistical analysis of fine-grained process data.

#### 2.1.5 Maturity Level 5: Optimizing

The organization uses a quantitative approach to understand the variation inherent in the process and the causes of process outcomes, and focuses on continually improving process performance through incremental and innovative process and technological improvements. The organization is concerned with overall organizational performance using data collected from multiple projects. Analysis of the data identifies shortfalls or gaps in performance. These

gaps are used to drive organizational process improvement that generates measureable improvement in performance.
The organization's quality and process performance objectives are established, continually revised to reflect changing business objectives and organizational performance, and used as criteria in managing process improvement. The effects of deployed process improvements are measured using statistical and other quantitative techniques and compared to quality and process performance objectives. The project's defined processes, the organization's set of standard processes, and supporting technology are targets of measurable improvement activities.

## 2.2 Maturity Level in NPD

Quintella and Rocha (2006) evaluated the PDP capability maturity level of two automaker plants in southern Rio de Janeiro state, Brazil, based on the CMMI criteria, revealing the existence of a planned, executed, measured and controlled PDP. It was also found that the existing practices were maintained even during periods of crises and that the experience can be replicated in new projects, i.e., both companies achieved the equivalent to ML 2 (Managed).
Organizations can achieve progressive improvements in their maturity by achieving control first at the project level and continuing to the most advanced level—organization-wide performance management and continuous process improvement—using both qualitative and quantitative data to make decisions (SEI, 2010). Therefore, gaps to achieve higher MLs have been mapped by the authors: in both companies, processes/subprocesses were not well characterized and understood in statistical terms, nor described in standards, procedures, tools, and methods, and improved over time. Predictions, if existent, were not reliable, due to the lack of statistical control and other quantitative techniques.
Focusing on NPD/PDP, such statement does not bring any surprising aspect, considering the odds reported related to success/fail rate in this area (Baxter, 1995; Duber-Smith & Black, 2012) and corroborated by Hollins and Pugh (1990), Miller (1993), and Muniz Jr. (2010): The design phase represents only 5% of the total costs of developing a product, but established 70% to 80% of its operating costs. However, mortality, since the basic idea until it becomes a profitable product, is as high as 95%. Van Kleef (2006) indicated that NPD failure rates ranged between 25 and 67%.
The question that comes up is: how to achieve higher MLs, with processes/subprocesses well characterized, understood, and controlled in statistical and other quantitative techniques terms, described in standards, procedures, tools, and methods, and improved over time, in an environment with such high failure rate? The answer would be related to increasing the hit rate (success rate) in projects and NPD/PDP and keeping it under control.
To do so, the use of SBCE can provide a reliable and robust pathway toward the excellence in those areas. Fundamentals of this method are described ahead.

## 2.3 Set-based Concurrent Engineering

The SBCE establishes that acceptable design solutions are developed simultaneously, at the intersection of product capability, process and solution alternatives, postponing final concept decisions, and taking advantage of initial flexibility/freedom to change and fully exploit alternative solutions (Morgan & Liker, 2006). It contrasts to the traditional design practice of "point-based design" (Qureshi, 2011), which "funnels" the decisions, closing possibilities as quick as possible, by determining the approximate design solution early in the project.
Along the development, the set of alternatives will be gradually narrowed, eliminating weaker solutions: what appears infeasible and/or too inferior is discarded, while what remains

acceptable continues to be studied, overlapping development activities (Costa & Sobek II, 2003; Eisto et al., 2001; Khan et al., 2011; Morgan & Liker, 2006; Recuk et al., 2006).

The concept of developing multiple design alternatives in parallel seems to be counterintuitive, expensive and inefficient (Liker & Morgan, 2006; Ward et al., 1995). But, it prevent good ideas' premature abandonment, reducing development risks, reworks rates, and development time. The risk reduction on SBCE occurs due to redundancy, robustness, and knowledge absorption (Kennedy, 2003).

As it can be inferred, the use of SBCE could count on increasing the project and NPD/PDP success rate, required to achieve higher company levels of maturity. Deployment of such strategy and performance predictions is discussed ahead.

# 3 Methods and Techniques

The research was performed at a Development Centre located in a commercial vehicle manufacturing plant installed in the southern Rio de Janeiro state, Brazil. With approximately 4,500 people and a production capacity of 300 units per day, the unit develops new models and new technology-embedded products.

The Concept Design Team at the studied company develops three concepts (three ideas) for each feature, mechanism or project subsystem. A new product being developed based on an existing 25 Ton 6 x 2 vehicle platform has been selected for the study. Initial figures estimated a total of twelve new concepts to be developed to customize the existing platform to the new product requirements, in areas such as powertrain and injection system, brake system, fuel tank, harness, chassis and suspension, etc.

Data collection, analysis, and simulation were performed along a seven-month period, while the product concept was developed, with technical discussions and meetings with the Design Concept manager and members of the development team.

# 4 Results and Discussion

Since there must be a compromise between the factors that add value to the product and those that cause cost increase (Baxter, 1995), a disadvantage of the SBCE would be the fact that it requires more people to develop the multiple solutions (Sobek II et al., 1999).

However, Rocha et al., (2012a) refute such idea, based on a theoretical model of PDP gain through the use of multiple-concept, comparing the additional manpower required to develop more than one concept at a time versus the project reliability increment (thus design rework reduction). Based on the additional resources required for multiple-design development, the authors deducted the gain (G) provided by the use of multiple-concept shown in Eq. (1).

$$G = 10 \log [(1 - (1 - Ta)^c)^n / (Ta^n c)] \quad (1)$$

where *Ta* is the Average concept (idea) success rate; *c* is the Quantity of different concepts for each design area; and *n* is the Quantity of design areas (areas requiring the development of new concepts).

Since the group had no historic data to establish its idea/concept success rate, Baxter (1995) figures were used: 1.3 out of three ideas being launched. Therefore, this study took the estimate of *Ta* = 43.3% (1.3 divided by 3). Calculating G (with *Ta* = 0.433; *c* = 3; and *n* = 12), the gain of 28.34 confirms the advantage to use multiple concepts on automotive PDP. Such result confirms the expected contribution of the SBCE use to improve the overall PDP quality, in terms of cost-benefit analysis.

Such Equation is based on the authors statement that if the odds of developing a winner project concept were 43.3%, product project requiring twelve new concepts would have a 0.0043% "do-it-right-the-first-time" success rate ($0.433^{12}$ = 0.0043%), whereas, developing three concept simultaneously (for each concept area, i.e. each of the twelve 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 18.23% situation, i.e. [$(1 – 0.433)^3$ = 18.23%]. Therefore, since the odds of each successful concept area would be, now, 81.77% (1 – 18.23%), the overall expected success rate would be close to 9% ($0.8177^{12}$ = 8.94%). Even though 9% seems to be a modest figure, it represents a huge leap from the original condition of 0.0043% (more than 2,000 times improvement).

As it can be inferred, besides the advantage in terms of NPD/PDP reliability, the use of SBCE can also help making performance previsions, as long as historical data about design success rate is known.

# 5 Conclusion

Unlike the PDP common practices, in which one seeks to establish the design concepts as early as possible, so that design can be frozen (usually being established as a project milestone), this paper asserts that the development of multiple concepts and decisions postponement might lead to considerable project development benefits, substantially increasing the chance of success, design reliability, with time and cost reductions.

Such benefits can be translated into higher maturity levels in NPD/PDP: processes/subprocesses well characterized and understood, described in standards, procedures, tools, and methods, would represent the equivalent to ML 3 (as per CMMI guidelines). If understood and managed in statistical terms, enabling performance predictions, as shown at the studied case, it would allow achieving the ML 4.

Even though NPD/PDP quality and reliability are increased through the simultaneous development of multiple design concepts, the expected incremental effort and resource usage to do so fades out. Rather, resource usage, development time, and costs are reduced, due to a rationale described by Sobek II and Ward (1996): Traditional problem-solving approach is first generating a lot of possibilities, then analyzing them and weighing pros and cons. Based on analysis and judgment, the most promising idea is chosen and developed, and changes are made where appropriate for improvement until a satisfactory solution emerges. In a trial-error process, if the solution proves infeasible, the process starts over. The design loops occurs because, every change causes further changes and analysis along the organization and stakeholders, resulting in rework and severe cost and time impacts, with no convergence prediction possible.

Based on a real project situation, the article findings indicate that organizations can take advantage of use the SBCE to increase the NPD/PDP maturity level, maximizing returns on investments in new product development, fulfilling customer needs faster and more reliably. However, further research must be conducted, raising historical data rates of success / error in specific industries, enabling a more robust analysis and definition of the optimum amount of concepts to be developed.

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