Set-Based Concurrent Engineering (SBCE) and TRIZ – A Framework for Global Product Development

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Abstract:

Continuously increasing complexity in the modern day systems call for radically different approaches to ensure high levels of functionality, quality and performance in new product development. Increasing globalization indicates that the world will witness more of Global Product Development (GPD). Further the problems of new product developers are compounded due to great amount of software that is embedded in many products. The non-physical nature of software systems, where intuition, experience and judgment of experts plays more important role than quantitative and measurable metrics of the traditional engineering world, increases the complexity for the global product developers.

This paper proposes a framework for GPD combining TRIZ (Theory of Inventive Problem solving) and Set Based Concurrent Engineering (SBCE) pioneered by Toyota. We propose that such a framework is ideally suited to be adopted and adapted for global product development. Set Based Concurrent Engineering (SBCE) as a process for developing new products has started gaining traction for global product development. However, given the counter-intuitive methods of SBCE pioneered by Toyota, where in, time spent in the early phases of development typically is more due very nature of SBCE, GPD projects are finding it difficult to adapt to this process. We propose in this paper how TRIZ based SBCE framework will make the GPD projects efficient, more robust and faster in many different GPD scenarios. Further it is proposed that principles of SBCE as practiced by Toyota Motors are natural fit for Global Product Development. However, the SBCE principles of *mapping the design space*, *conceptual robustness, and integration by intersection*, and, *feasibility before commitment*, need a set of tools and techniques to create an evolving picture of the situation at a particular point of time for all stakeholders in the process of development. The TRIZ based SBCE framework specifically takes care of information complexity, structural complexity, decision complexity and organization complexity of the GPD projects. TRIZ concepts of *ideality*, *functionality, resources and contradictions* elimination are used to come up with inventive solutions to sub-system functionality. TRIZ is used to generate a set of alternatives or possible solutions to various sub-systems to be made in the design space. The number of alternatives reduces gradually as the project is executed and more clarity about the components emerges. However, the goal of SBCE is to keep the alternatives till as late as possible. TRIZ helps in creating alternatives maintaining this picture and keeping all the alternatives during the whole life cycle of the project.

Introduction

In a 2006 *Businessweek* research report [1], it is mentioned that "… most manufacturers understand what Global Product Development (GPD) is and why it is important but few really understand *how* to make it successful". The problems that new product development teams face – the so called "fuzzy front" of the product development life cycle, are further accentuated when the teams for product development are dispersed around the globe and they work together to conceive, design and develop new products. The commercial value proposition of such distributed Global Product Development scenarios – be it time to market, cost of the new product development, innovation or quality/robustness of the design, is making it increasingly difficult for large product companies to not to embrace the GPD as a way ahead in their business strategies.

The problems however, are much deeper. The product development processes, methodologies, frameworks and systems that have worked in the past for many companies, as were developed by co-located teams- taking advantage of hard to quantify cross-functional interactions, informal collaborations on high bandwidth communications including face to face discussions [7]. These interactions are either vanished or have reduced considerably in the globally dispersed, culturally un-adjusted, *non-e-mail* communication minimized, and physically unaware teams that are spread over thousands of miles to collaborate on new product development – that continues to be "Fuzzy".

Yet there are three interesting actors (for the purpose of the paper actors include companies, techniques, methods, concepts, etc) in the Global Product Development scenarios that are emerging as potential winners – all three are emerging and thriving in the new globalizing world. It is imperative that the GPD companies should study, analyze and imbibe these or combine these or their variants to come up with their own strategies and execution methods. Else, the winners of the last world will end up ending their top ranks in the global innovation complexity that Globalizing world is creating everyday. Author's research indicates the winning actors are three – two companies and a methodology that has come up as practically the only worthwhile innovation method, i.e., TRIZ. The two Global companies that have embraced different means and methods are Toyota Motors and Proctor and Gamble. However, the underlying methods that these companies have embraced or designed – namely Lean and Open Innovation (or Connect & Develop in P&G parlance) are the key for their success in the Global Product Development scenarios.

This paper proposes a new framework combining elements from Lean product development – namely the Set-Based Concurrent Engineering (SBCE) pioneered by Toyota and some of the elements of Open Innovation to be combined with TRIZ as a base methodology for succeeding in the Global Product Development scenarios. The next section gives a brief overview of emerging global product development scenarios. Section 3 and Section 4 give brief overviews of SBCE and TRIZ respectively. The GPD Framework is described in detail in Section 5. Finally conclusions and further pointers for research and future development are given in Section 6.

2. Global Product Development

In the globalizing world new products do not need to be developed end-to-end at one place. Chunks of product development needs or desired functions from a product can now be outsourced to other organizations or other geographic locations, depending on cost-based, competency-based or market-based strategies. The value proposition of leveraging global capabilities is enforcing enterprises that used to focus on depth-based strategies for specialized offerings to look forward to collaborating with other organizations with possibly different strengths to develop newer products faster. There are two key dimensions identified for global development scenarios. Using these dimensions there emerge six distinct Global Product Development Scenarios [3]. These scenarios are summarized in Table 1.

Table 1: Global Product Development Dimensions and Scenarios

GPD Scenarios	Geographical Boundaries		Organizational Boundaries		
	Near-Shoring (same country)	Off-Shoring (across countries and continents)	In-house (within same enterprise)	Out-Sourced (across different enterprises – client vendor relation)	Collaborated (across different enterprises – peer to peer relation)
Outsourced – Near-shoring	√			√	
Outsourced – Off-shoring		√		√	
In-house – Near-shoring	√		√		
In-house – Off-shoring		√	√		
Collaborated – Near-shoring	√				√
Collaborated – Off-shoring		√			√

Key enablers of global product development have been listed down in [11] as (a) Fully digital product development process (b) Internet connectivity for business (c) Global skilled labor market (d) International collaboration experience. However, the process and product architecture themselves continue to be based on old methods of centralized control and centralized management. Product development process and product architecture methods need to be aligned to demands of the Global Product Development scenarios. Most companies although leveraging the global opportunities in the six global development scenarios – still are not able to transition to the demands of the new networked world. The new globalizing world demands decentralized control – as exemplified by self-organizing networks. The managers and leaders trained in the methods of achieving success in the previous world still talk about how to assign work, how to align and how to control. The realization that so called managerial control is a myth in a self-organizing and continuously evolving enterprise has not yet sunk in most of the enterprises. However, Toyota and P&G are two clear examples of global enterprises that have traditionally redefined success with agility in changing global scenarios.

P&G call its Open Innovation initiative as Connect & Develop (C&D). One of the most visible open innovation programs in the world that is helping P&G to enlarge its capabilities across the Globe [16]. The P&G's C&D program is based on connections. Developing connections with institutes, organizations, individuals, SME, and, even P&G's competitors across the Globe to solve and fulfill P&Gs customer's needs is the hallmark of this program. Fifty percent of new product revenue is slated to come from connections developed as per this program. The concept is to expand the idea base through the connections and then choose and develop what can be considered ideal solution at the moment. Open innovation is the next trend in the organization dimension stated in Table 1. The boundaries of organization starting from in-house, outsourced, collaborated and open Innovation can be construed as a trend that organizations may need to move to next stage wherever they are in trend.

Lean or Toyota Production System (TPS) has already shown to the world the value of Leaning and incorporating problem solving at the basic unit, i.e., an individual is the key to create an enterprise that has the confidence to embrace change continuously. The results are impressive to say the least, as Toyota is on its way to be number one [18]. Focusing on customer value and religiously making it flow through the processes or value streams as they call is fundamental to Lean or TPS. Many enterprises have embraced it partially or fully, but the successes that Toyota achieves have yet to be seen in other embracers of Lean. However, the techniques used by Toyota for product design are so counter intuitive that not many companies have even dared to evaluate them for incorporating in their product design methods. May be, there in, lies the success of Toyota product development process. It is actually not a process at all. A process that eyes accustomed to overdoses of process mappings and business process automation find it difficult to find the hidden value of learning and self-organizing that Toyota imbibes naturally and intuitively. However, one such attempt has been in the articulation of Set-Based Concurrent Engineering (SBCE) as a method of developing new products.

3. Set Based Concurrent Engineering

Set-based concurrent engineering is a development technique invented by Toyota, which focuses on collaboration between different departments. The aim is at shorter development times with an increased quality level by improving collaboration and by parallelizing parts of development process. In the traditional point based approaches the teams select an initial design option and work on quickly producing it – however, the design gets modified as new information, experiences and requirements emerge thereby creating what is called "Design Churn" effect. In this scenario, the product remains in development phase for very long period as the chain reactions created by many modifications to initial design lead to continuous refinement and an evolutionary design that keeps on going. This is the result of early design convergence and action-oriented approaches most companies and management gurus' prophesize. In contrast Toyota's SBCE advocates slow convergence strategy. SBCE processes starts with large design alternatives covering broad design spaces and then slowly converges to a possible design by eliminating the weakest alternatives rather than choosing one "best" alternative. It is a counter-intuitive approach and looks paradoxical to people trained in the traditional point based approaches. Various sets of alternatives are taken ahead for all parts of the product and the weakest ones are eliminated as we move in the product development life cycle. Figure 1 contrasts the two approaches.

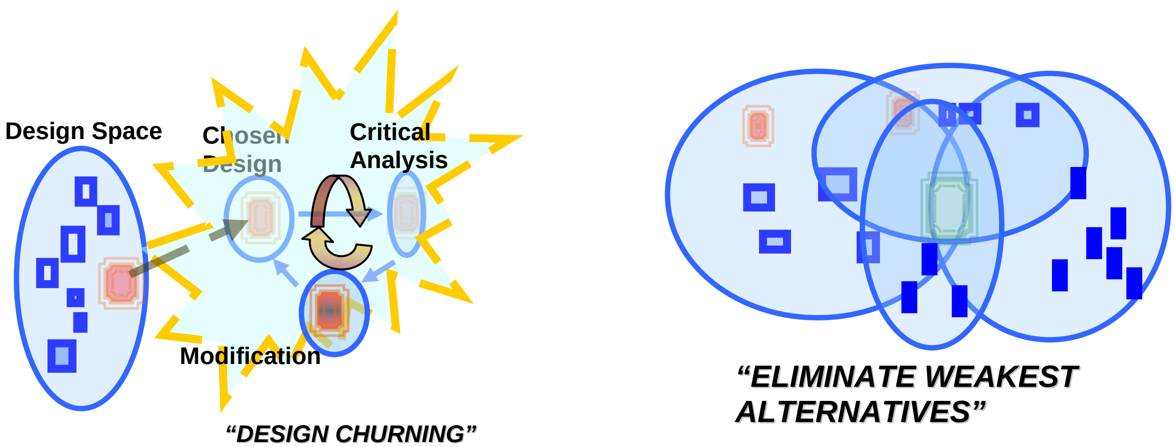

Figure 1: The Traditional Point Based Approach - Design Churning Vs Toyota' SBCE by Emergence by elimination of weakest

A comparison of two approaches is given in Table 2 below.

Table 2: A Comparison of Point based and Set-based approaches

Conventional Point Based Approach	Set-based Concurrent Engineering
• Modify an initial solution and optimize at each stage • Large iteration loops are distinct possibilities especially in large, rapidly changing, unpredictable project environments • Based on Serial and Iterative workflow, which does not allow much flexibility and agility	• Consider a large set of Solutions and start eliminating the weaker ones, until the optimal is left or evolved • Work in parallel on several components of the product even if they must work together • Large sets of solutions imply higher probability of finding optimal solutions • The process reduces the probability of starting all over again • Takes less time to find optimal

	solution • **Probability of finding optimal solution much higher than the point based approaches**

SBCE leading to slow convergence seems like an inefficient and expensive way to develop products, however, Toyota creates new automobiles faster than industry average with less effort. It has been termed as the Second Toyota Paradox – as more time spent in early phases of the product life cycle leads to less time spent in the overall product life cycle [24]. Five main principles of SBCE as articulated in [15] are summarized in Table 3.

Table 3: Five Main Principles of SBCE

Mapping the Design Space	**Striving for Conceptual Robustness**	**Feasibility before commitment**	**Integration by Intersection**	**Conflict Handling**
• All functional departments identify the solution space independent of others • Communication between departments is based on Design Spaces – Not on Single Ideas • Discussion is kept vague and abstract	• Design remains functional after variations in its environment • Will the Design still fit the solution space after some time? • Create Designs that work regardless of what the rest of the team decides to do	• Multiple concepts considered in parallel – prototypes created and infeasible ones eliminated • Each concept is analyzed from the reasons why a concept is still (in) feasible and the role and impact of problem in the overall product	• Overlap of feasible design spaces of the different sub systems – directly translatable into acceptable solutions • A decision once taken has to be respected by all • Taking late decisions means that more importance has to be given to the decision and hence more effort should be spent	• Client Assisted Design Advice System – Solutions that meet the needs of the customer based on - (a) Equality between all related parties (b) Avoiding asymmetric dissatisfaction to any party in particular • Equality of priorities of different points of view • Two types of subsets of problems (a) Competition vs Cooperation (b) Domain Level Vs Control Level Conflicts

SBCE reduces the cost of taking back a *decision* earlier made; hence there is more room to improve the concept while developing it. Wrong decisions in later phases of the development process do not have much impact on cost and are far less time-consuming than if these would have been made in beginning. Further SBCE minimizes the cost of iterations by not only reducing the number of iterations but substantially improving the cycle time of iterations. SBCE using Decision Dependency Matrices (DDM) [5] has been proposed in [6].

Although SBCE is known for many years and many research publications have described the process, it has not been picked up by many companies as principles are counter intuitive and in time and budget constrained commercial organizations, it becomes very difficult to not to show one design quickly so as to show the development project is on the right track to the top management. The information, decision, design and organization complexity also increases as SBCE as a process requires strict discipline in following the process by everyone as there is no central control, it creates a self-organizing system. Further, the SBCE principles don't describe specific methods, techniques, tools or frameworks for execution. It is this important gap that TRIZ (Theory of Inventive Problem Solving) can help in bridging for the global product development scenarios. In the next section, a brief overview of TRIZ is given before proposing the TRIZ based SBCE framework for GPD.

4. Theory of Inventive Problem Solving – TRIZ

TRIZ (pronounced *TREEZ*) is the Russian acronym for the *Theory of Inventive Problem Solving*. It is a large collection of empirical methods discovered and invented through comprehensive studies of millions of Patents and other inventions for problem formulation and possible solution directions. This proven *algorithmic approach* to solving technical problems began in 1946 when the Russian engineer and scientist Genrich Altshuller studied thousands of patents and noticed certain patterns. From these patterns he discovered that the evolution of a technical system is not a random process, but is governed by certain objective laws. These laws can be used to *consciously* develop a system along its path of technical evolution - *by determining and implementing innovations*. [26]. TRIZ states that someone, somewhere, sometime has solved the problem that you are facing or a very similar one, it is now a much easier task to search for the solution rather than thinking about solution with your limited exposure. By abstracting the inventiveness of thousands of inventors, TRIZ brings to the problem solver a plethora of robust techniques and methods that has worked in the past substantially. TRIZ clearly distinguishes two main parts of problem solving – Problem description or definition and its solution -

- Define, Describe, Analyze the problem from multiple perspectives, as deep and as wide as one can go. This requires a focused discipline to "not to jump to solution immediately" – TRIZ has tools and Processes for Problem Definition

- Find out the root contradiction and look at how the contradiction has been solved in the past – Solve by exploring in multiple directions but start from the end result – The Ideal Final Result – Focus on Functionality not features.

TRIZ has variety of techniques for problem formulation and problem solving there are texts available that describe TRIZ in detail. Reader can refer to large body of knowledge at [27]. However Table 4 below lists down main techniques and tools of TRIZ applicable at various stages of problem solving. The following table includes TRIZ tools in the popular version of TRIZ that might have been influenced by some other fields and not necessarily the classical TRIZ techniques.

Table 4: A Brief Summary of Main TRIZ Tools for Problem Formulation and Solution

TRIZ Tools for problem formulation	TRIZ Tools for problem solving
Focus on Function – Main Useful function that product needs to deliver to meet a customer/user need	Technical Contradictions – Inventive Principles – when two parameters interact with each other and one cannot have best value of both parameters
Value is nothing but Function delivered to meet a user need	Physical Contradictions – when the problem is to have different value of the same parameter, e.g. Coffee mug needs to be hot from inside but cold from outside
Ideal Final Result – Value delivered at no cost or resource expenditure and not harming the system in anyway, alternatively the function is achieved on its own – self functioning system	Trends of Evolution – there were 8 trends that Altshuller identified. These have been expanded to many more by researchers after him
How does the problem/situation looks in space and time – using what in literature is called the Nine Windows Approach	Resources – Are all the resources utilized fully – even the harmful resources as well
How does the problem looks in depth and scope – by using Why-What Hierarchy	Knowledge and effects – the codified knowledge of how others have achieved a particular function, e.g., cleaning solids
What are the resources available and what the constraints in and around the problem	Ideal Final Result – How to take the system closer to IFR rather than focusing on current issues – can a method be devised to achieve IFR
Function and attribute analysis	S – Fields and Standard solutions
S-Curve analysis – where the field is on the S curve and where the product that needs to be designed for customer needs should focus on	Psychological Inertia tools that TRIZ has to take the inventors mind away from the tunnels of core competence that restricts exploration of other fields.
	Anticipatory Failure Determination (AFD) or Subversion Analysis – Inventing failures to create robust designs

With this brief introduction we shift our focus to how SBCE and TRIZ can be combined to create a framework for Global Product development scenarios.

5. TRIZ Based SBCE Framework for GPD

We will describe the generic framework and possibilities before looking at specific GPD scenarios. First step as a process we propose for all GPD scenarios – the SBCE as defined in Section 3 will be the key principles on which the framework is based on. Hence we have to follow the protocols described in the SBCE approach. Further there are clearly defined teams or departments with specific expertise and expertise level available upfront – whether they are geographically dispersed or in the vicinity of each other, are not relevant for the time being. Table 5 below describes the TRIZ based SBCE framework for Global Product Development. There are other tools and techniques that have been mapped. These techniques not from TRIZ however fill the gaps where TRIZ doesn't provide a readymade technique such as alternatives evaluation, conflict handling, etc. However, it is up to the ingenuity of the formulator in how he or she can use TRIZ for such cases as well.

Table 5: SBCE and TRIZ for GPD

SBCE Steps	Specific Actions	TRIZ and Other tools
Mapping the Design Space (Functional Team level)	• Describe user needs • In case of multiple needs carry out needs interdependency analysis • Find out key functions to be performed • Function dependency analysis to find out interdependencies • Can some high level functions specific to strengths of different teams be identified • Let each team explore the specifications, needs, functions independent of each other • Each team explore design tradeoffs through simulations and their past observations • Each team should come up with their sets of different solutions with in the functional and performance needs of the product	<u>Problem Formulation and Analysis</u> • Ideal Final Result (IFR) • Why-what hierarchy • Nine windows • Dependency Structure Matrix (DSM) [28] • Function/Attribute Analysis • System Complexity Estimator (SCE) [4] • S curve analysis <u>Searching for Solutions</u> • Contradictions – Technical/Physical • Trends of evolution
Striving for Conceptual Robustness (Functional Team level)	• Design should remain functional after variations in its environment • Vulnerability of system to changes in the environment should be minimized • Modularized Design with standard components	• IFR • AFD/Subversion Analysis • Robust Inventive System Design (RISD) [7] • DSM
Integration by Intersection (System level)	• How are the parts integrated to meet at the point that will be regarded best solution • Find out overlap of feasible design spaces for each sub component	• Decision Dependency Matrices (DDM) [5, 6] • Analytic Hierarchy Process (AHP) [8, 14, 22]

	• Decisions about eliminating the weak designs	• Technical Contradictions (TC)/ Inventive Principles (IP)
Establish Feasibility before Commitment	• Multiple concepts developed using prototyping simulation • The infeasible ones will be rejected rest all will continue to be developed	• Decision theoretic principles [20, 21] • AHP • Closer to IFR
Conflict Handling	• Cooperative Conflict handling	• Which solution is closer to IFR? • DDM • AHP

Table 6 describes specific tools and techniques that may be more relevant in the six GPD scenarios described in Table 1 above. The ratings below indicate how much TRIZ compared to other tools and techniques described in Table 5 are important in GPD scenarios and to meet specific SBCE principles. A High rating indicates that TRIZ is the most important technique for the specific phase. A medium rating indicates that other tools are more important than TRIZ and may be used more extensively. A Low rating indicates that TRIZ is not easy to apply in those scenarios and definitely other tools exist that should suffice.

Table 6: Relative relevance of TRIZ with respect to other tools in the GPD scenarios

GPD Scenarios	Mapping the Design Space	Striving for Conceptual Robustness	Feasibility before commitment	Integration by Intersection	Conflict Handling
Outsourced – Near-shoring	**Medium**	**High**	**Low**	**Medium**	**Low**
Outsourced – Off-shoring	**Medium**	**High**	**Low**	**Low**	**Low**
In-house – Near-shoring	**High**	**High**	**Low**	**Medium**	**Low**
In-house – Off-shoring	**Medium**	**High**	**Low**	**Low**	**Low**
Collaborated – Near-shoring	**High**	**High**	**Low**	**Medium**	**Low**
Collaborated – Off-shoring	**Medium**	**High**	**Low**	**Low**	**Low**

The value of Table 6 is for creating TRIZ awareness and skills in the specific GPD scenario that the company might be involved. The value of TRIZ is clearly seen in mapping the design space and striving for conceptual robustness. As of now we do not have any other technique that helps create conceptual robustness of design hence TRIZ scores on that are considerably. Given that conceptual robustness is the main need on which the GPD scenarios are really based, the success of product development in the SBCE process depends on how quickly and easily the teams embrace TRIZ.

6. Conclusions and Further Research

Product development in the globalizing world is becoming global. However, the methods and techniques needed for Global Product Development (GPD) have not evolved as rapidly. Open Innovation as practiced by P&G and Set Based Concurrent Engineering (SBCE) as practiced and proved by Toyota are the new methodologies that can come as the savior for Global product development teams. These methodologies however need set of techniques and tools that can address the specific demands of SBCE for GPD.

In this paper, we have proposed a TRIZ based SBCE framework for GPD. Further we have found TRIZ to be best suited to specific phases, i.e., mapping the design space and striving for conceptual robustness of the parts. We believe that the combination of TRIZ with SBCE will cater to the exploding needs of GPD. We will be developing the framework further as we go on deploying and using it. We intend to use the framework in specific scenarios and see the results – may be by TRIZCON 08.

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