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DFMA & Lean 3z Thinking

(Steps towards a failure-free innovation process)

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Abstract:
The innovation process is still the business process with the highest failure rate. During the last few decades a multitude of different approaches for supporting innovation have appeared on the scene. Perhaps each one of them has useful aspects that could help to improve innovation in any company. However, the lack of integration of those approaches causes confusion and makes it difficult and expensive to implement them.
Although each of these methods has proved its effectiveness, implementing them as separated tools may become overwhelming, as the absence of integration increases enormously the learning curve and costs of implementation. Several of these methods are also supported with software tools that facilitate implementation, however, those software tools are also affected by the same or perhaps a worse shortage of integration. It is mandatory to develop a support for robust, rapid innovation cycles to accelerate innovation by reducing, and, possibly, eliminating uncertainties.
This paper refers to the development of an integrated approach to innovation methods including design thinking, Kansei engineering, QFD/VOC, blue ocean strategy, technology surveillance, TRIZ, A3, functional analysis, value engineering, set-based concurrent engineering (SBCE) and design for manufacturing and assembly, as these methodologies have the highest potential for improving the effectiveness and likelihood of success of the innovation process while at the same time reducing risks and costs.

1. Introduction

The innovation process is a complex system of activities required for taking advantage of opportunities in the market. It is an information generating process, which starts with an abstract, uncertain, confused description of a new market opportunity. At the fuzzy front end the ideas for taking advantage of the new need are generated; that means going forward with uncertain information until the uncertainty may be overcome with information obtained through analysis of the results.
This traditional trial and error approach is expensive and time consuming. During recent decades an overwhelming multitude of different approaches for supporting innovation have appeared on the scene. Although perhaps each one of them has useful aspects that could help improve the innovation process [1], efficiently and effectively supporting it with methods and computational tools is limited due to the lack of integration of the these available methods and tools. The myriad of innovation tools and methods that are around today may be confusing and overwhelming, as may be observed in Figure 1.

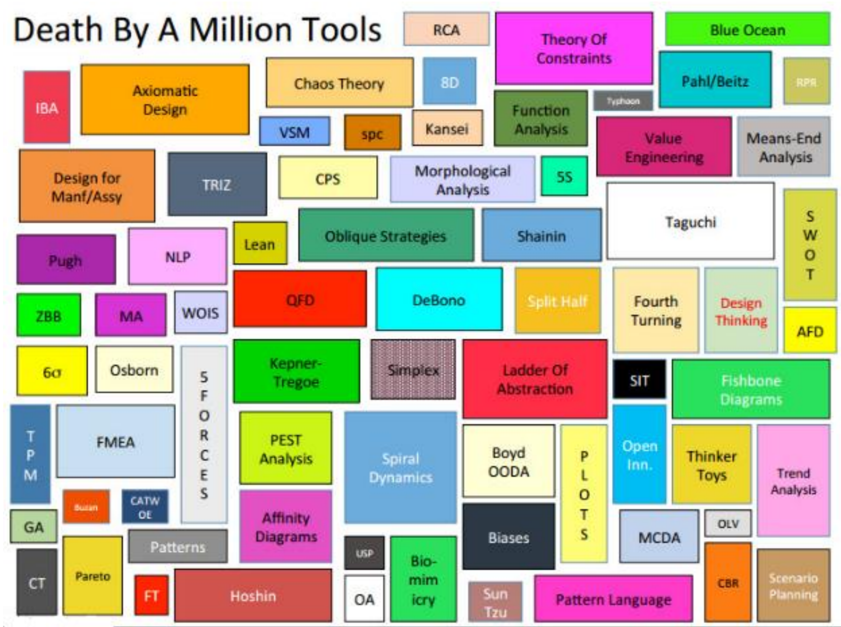


Figure 1
Death by a Million Tools [1]

Consequently, the innovation process unfortunately continues to be the process with the highest failure rate. As Philip Samuels et.al. [2] comment, “Most innovations fail. Most executives are unhappy with the predictability, scalability and repeatability of the innovation process”.
This paper will discuss Innovation Management & Sustainable Technologies, the research work previously initiated at the Monterrey Institute of Technology (Mexico) aimed at the integration of innovation tools and methods to increase effectiveness and reliability.
The first steps were focused on integrating QFD (quality function deployment) [3], functional analysis and TRIZ (the Russian acronym for theory for inventive problem solving) and patterns of evolution) [4] and were followed with analysis regarding the integration of TRIZ and CAD [5]. These steps were devoted to contributing to a reduction in product development time and to an improvement in quality and performance by creating the groundwork for integrating interactions between product development tools and methods.
This paper discusses the development of a new framework that integrates the best innovation methods and tools, comprising design thinking, Kansei engineering, QFD/VOC, blue ocean strategy, technology surveillance, TRIZ, A3, functional analysis, value engineering, set-based concurrent engineering (SBCE) and design for manufacturing and assembly, as these methodologies have the highest potential to improve the effectiveness and likelihood of success of the innovation process, while at the same time reducing risks and costs, thus contributing to achieve robust, rapid innovation cycles by accelerating innovation and reducing and probably eliminating failures.
The first step was to identify and set up a generic model of an innovation process in which it is possible to map all methods, according to the kind of activity related to such a model. The resulting innovation model represents a framework for organizations with innovation as a fundamental process in their activity to increase their competitiveness, efficiency and progress.

Several sources have been consulted, and one in particular used as the reference was the standard UNE 166002:2006: Requirements for the management system of innovation, research and development (24). This document proposes a model consisting of seven criteria. The first two are based on the need to acquire an innovative culture that provides the organization, the environment and the necessary means to carry out the activities included in the following criteria, called innovation activities and refer to what the organization allocated to it in innovation and resources. Intermediate criteria are those that are directly related to the innovation process. The last criterion concerns the results generated with these activities, which lead to the development or improvement of new products, processes or services, and value creation in the organization that affect its culture and strategy. The resulting model has a cyclical nature.

Another key document consulted was the Global Competitiveness Report (23), published by the World Economic Forum. It states that innovation is particularly important for economies because as they approach the frontiers of knowledge and the possibility of integrating and adapting exogenous technologies tends to disappear, the importance of creating new and innovative products is an important factor for the development of any country. Companies in these countries must design and develop cutting-edge products and processes to maintain a competitive advantage. This requires an environment that fosters innovative activity and protection of intellectual property.

2. The Fuzzy Front End

At the fuzzy front end of the innovation process several approaches, such as QFD/VOC, blue ocean strategy, design thinking and Kansei engineering, are helpful in reducing uncertainty. Each of them contains valuable useful guidelines with the potential for eliminating uncertainties and ensuring one straightforward path to success. However, the long learning curve and implementation time discourages use of them and, consequently, most innovation initiatives are taken based more on inspiration and intuitive decisions that stand as the main source of the tremendous failure rates and enormous costs produced by those failures.

What if we could find ways of reducing the learning curve and accelerating their implementation?

The following are the basic thoughts that might lead to a new way of implementing the fuzzy front end as part of a whole “lean blue innovation” process, which contains the best of all those methods and tools, making its implementation straightforward. Of course, it is not an easy endeavor and will require the collaborative work of many institutions. Our intention now is to highlight the benefits of the interfaces that are being recognized and that will make it possible to convert the innovation process into a structured approach that minimizes failures and costs.

2.1. QFD/VOC and the “buzz” of social networks

QFD is an engineering tool developed by Japan’s Yoji Akao [2], building on Deming’s work on statistical quality control. It was introduced as a method to ascertain relations between consumers’ necessities and engineering features. It is used extensively around the world and has become a deep-rooted product development method. QFD/VOC provides guidance for innovation and serves as a decision support tool for managers, marketing, and engineering with the aim to ensure that the key quality aspects that are important for customers are taken into consideration for guiding the decisions regarding the characteristics that should be improved in the products. At the kernel of the method is the “house of quality”, which provides a useful graphic representation for understanding interrelations between customers’ preferences, captured as the voice of customer (VOC), and products characteristics. (Figure 2)

Indeed, several software products support the creation of the HOQ by facilitating data introduction and analysis. However, the method’s biggest handicap is that it requires a long time for collecting data and analyzing it, and that discourages use of the method thoroughly, as often neither the time nor the resources are available, especially when it comes to launching new products on the market.

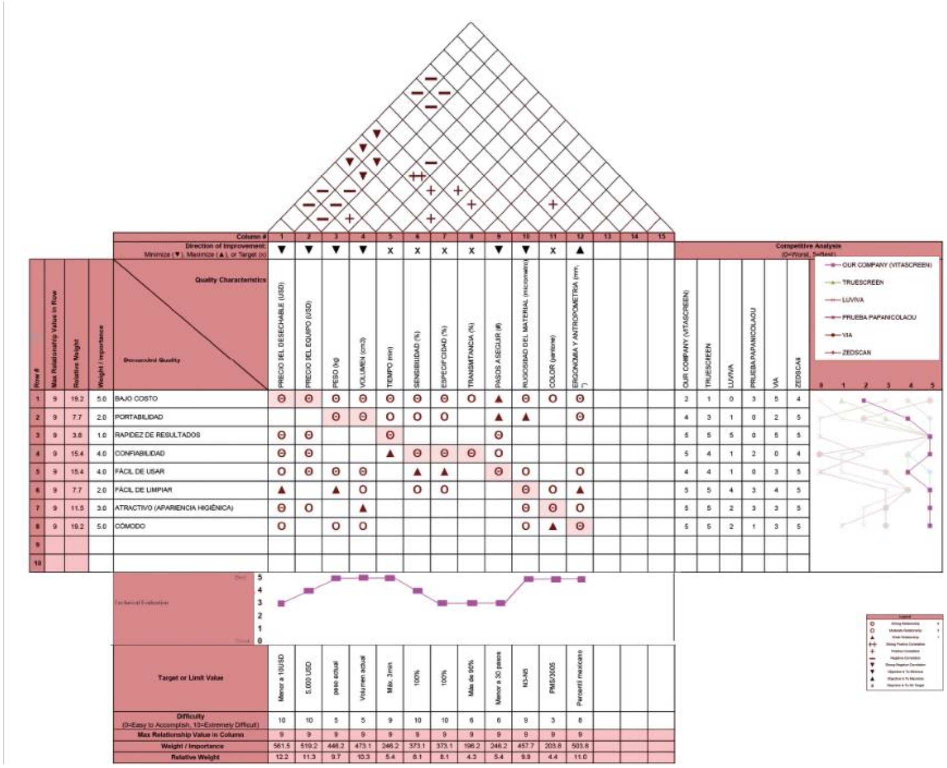


Figure 2. House of Quality

New possibilities that are being developed for capturing VOC through the “buzz” of social networks might enormously accelerate the time consuming and costly gathering of information, by also helping to eliminate the bias of partial observations or ill-defined interviews. Although the computational tools for capturing the social network “buzz” and for analyzing customers’ sentiments and intentions are in the early stages, some already offer useful guidance [6], [7].

Furthermore, computational simulations are being developed that produce insights providing the researcher with another tool to reason about challenging problems. According to current theory, innovations that are perceived by social groups as having greater compatibility will be adopted more rapidly than other innovations [8].

2.2. Design thinking and Kansei engineering

Design thinking is a recognized method for the practical, creative resolution of problems and establishment of solutions, with the intent of an improved future result. Brown [8], CEO and president of IDEO, is a leading proponent of design thinking as a method for meeting people’s needs and desires in a technologically viable and advantageously meaningful way. Design thinking is a form of solution-based, or solution-focused thinking, beginning with an objective (a better future situation) as an alternative for solving a specific problem [9, 10, 11]. It is a human-centered innovation process that emphasizes observation and collaboration; it contains opportunities of synergies with the concept of “going to the Gemba” of QFD/VOC. The HOQ facilitates the involvement of consumers, designers, and business people in an integrative analysis process that may be also complemented with Kansei engineering for translating the customer's psychological feelings and implicit needs, such as emotional experience, into the features of the new product. It was founded in the 1970s by Mitsuo Nagamachi [12], now professor emeritus of Hiroshima University. Since then Kansei engineering has been applied to a wide diversity of products, ranging from automobiles to electronics, aviation, food and underwear. It is often said that KE was first involved in the design of the Mazda Miata (also known as the MX-5).

As explained by Schütte [15], "KE does not develop new theories or tools in the different areas at all. Rather, it is an all-embracing methodology containing rules for how different tools can interact with each other in order to quantify the impact a certain product attribute has on the users' perception."

It is becoming evident that nowadays customer acquaintance with diverse viable options, combined with the demand for high quality products and services, is forcing producers to change from conservative 'product-out' thinking to a 'market-in' approach, challenging business by:

•How to help engineers address the emotional design needs of new classes of clients who are highly educated, multi-cultural, and comprehensively prepared and represent a diverse buying decision procedure?

• How your innovative products might be differentiated when they are rapidly tracked by low-priced clones?

• Customers who are increasingly making their buying decisions based on psychological and emotional appeal. How can your product and brand connect emotionally with them?

There are many interface possibilities that could be used for integrating these methods instead of excluding them from each other and making them more useful for eliminating trial and error from the conceptual product development. Workshops that link Kansei engineering and QFD are already offered [16] claiming "easily available Kansei engineering tools and software to apply QFD to the fuzzy emotional sides of product development for producing highly profitable, differentiated products and services".

An enhanced value may be added by also integrating design thinking. Evidently the challenge is to develop a seamless method of integration that is easily learned and expeditiously implemented.

3. The Definition of Business Strategy and Projects

3.1. Blue ocean strategy

Blue ocean strategy (BOS) is a business methodology focused on creating uncontested market space by increasing the buyer´s value while reducing costs. As Kim and Mauborgne [8] state, "Blue ocean strategy challenges companies to break out of the red ocean of bloody competition by creating uncontested market space that makes the competition irrelevant".

Frame and BOS tools include: strategic canvas, cost-value relationship (to be explained later as a technical contradiction in TRIZ), four actions framework, six basic paths, cycle of experiences of buyer, and services map to the purchaser.

Although at the present there are few success stories of companies that applied these theories in advance, the key concepts of BOS remain valid and may be implemented in a more straightforward way if integrated with QFD/VOC and the other methods mentioned. At the kernel of the BOS concept is the cost-value relationship, represented as an eye-catching figure of two intersecting triangles (Figure 3). These triangles represent the cost to be reduced or minimized (the upper triangle) and the performance (embodied by the lower triangle) to be increased or maximized. This paradoxical metaphor of maximizing the area of intersection represents the opportunity to create a breakthrough that allows break out of the "red ocean". Of course, if that were easy to do, each company would be implementing this strategy for maximizing its competitiveness.

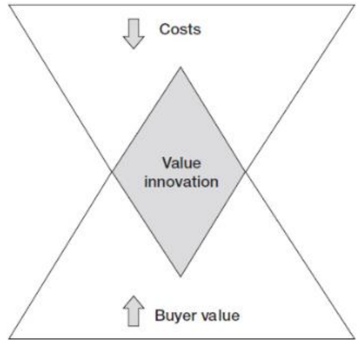


Figure 4. Blue ocean strategy: The simultaneous pursuits of differentiation and low cost [8]

The theory of inventive problem solving (TRIZ) contains several tools that are useful for structuring the ways to achieve the desired target. One of those tools is the concept of ideal final result (IFR), which states that the ideal solution of a technical contradiction should be that which enables increasing the usefulness of the product without introducing new harmful effects, maximizing the ideality. Ideality may be expressed as:

Ideality = Benefits / (Costs + Harm)

The ideal final result describes the state of a system performing the desired function, independently of the mechanism or constraints of the original problem. It is the upper limits of the "ideality" equation, and can be visualized as "ideal": The ideal system delivers benefit without harm (no undesired side effects.)
By removing the mental constraints of existing solutions, IFR gets people to think "out of the box" encouraging breakthrough thinking by enabling innovators to define the roadblocks they have to face. A written formulation of the IFR together with the strategy of blue ocean is very helpful in breaking down psychological inertia.

DT and IFR have in common acting as tools to imagine future states and bringing products, services, and experiences to market. The term design thinking is generally referred to as applying a designer's sensibility and methods to problem solving, no matter what the problem is. It is not a substitute for professional design or the art and craft of designing, but rather a methodology for innovation and enablement.

3.2. Technology surveillance and patterns of technological innovation

When the objectives are clarified (either reduce cost or increase value or both simultaneously) innovation projects may be defined. Now it may be stated that innovation is an interconnected process of many activities of observation and creativity, which should be integrally structured by a technology strategy that also helps as a means to understand and communicate product trends throughout the organization. In such a context, some challenges of innovation are the information processing about the environment, both in the technical field and in the market. Then business opportunities have to be identified, as well as the strategic key technologies that lead to the definition of strategic projects that develop into proactive product developments.
Technology surveillance is an organized, selective and permanent process to capture information on technology from the outside; select, analyze, disseminate, communicate it and turn it into knowledge to make decisions with less risk and to anticipate changes. But to achieve and develop more proactively the creative activities that lead to innovation, the TRIZ tool patterns of evolution

of technological systems helps to identify broader trends in the development of technical systems, which helps anticipate the improvements that are more likely to occur in the next stage of development of products or technology. The use of both tools helps to establish a link between the future and the present in order to determine how to accomplish the strategy. They are the future planning tools for structuring and strengthening the project portfolio.

The theoretical bases of classical TRIZ are the patterns of technological evolution. Technological evolution has its own laws and characteristics, which is why people from different countries working on the same problem independently obtained the same solution. Altshuller, the author of TRIZ, identified recurring patterns or regularities in the development and evolution of technological systems. Knowing these regularities makes solving technical problems much easier. Based on this discovery, Altshuller identified a group of patterns (regularities) describing the evolution of technology, as presented in the collection of global patent literature. He stated that if innovators could identify the current state of a given system, these patterns of evolution of the technological system would guide them to the next generation of the system.

4. Ideation Stage to Get Closer to the Desired Result

At this stage of the model we have already defined the actual situation in terms of the voice of the customer that led to defining the required performance parameters and targets, on the one hand, and on the other, the conceptual scenario derived from the strategy adopted. The next step is to move to the ideation stage. At this stage technical and physical contradictions are identified and several TRIZ tools help to develop inventive solutions.

Technical contradictions appear between product parameters and attributes when moving to the ideal solution wherever a function may be fulfilled, or another parameter or characteristic worsened. Although QFD is not a problem-solving tool, it is a likely tool to identify what has to be solved or improved to increase value in the product. Contradictory situations are easily displayed on the roof of the house of quality. When required, the elimination of technical or physical contradictions becomes the evaluation criteria for good innovative design solutions as those that move closer to the ideal result.

For solving contradictions, the contradiction matrix is a helpful alternative to brain storming, where inventive principles screened from the patent analysis help in overcoming the current contradiction with innovative solutions.

As the contradictory relationships among the design parameters are identified on the roof of the HOQ, it seems straightforward to use these identified contradictory parameters to find a link to Altshuller's contradiction matrix. In Figure 5 a simplified representation of the link between the HOQ diagram and the contradictions matrix is shown.

After analyzing parameters where contradictory relationships have been identified on the "roof" of the HOQ, the involved parameters are compared with the 39 generalized Altshuller parameters and then located in the contradiction matrix. By finding a match among the contradictory parameters from the HOQ and the 39 Altshuller parameters, the inventive principles that could be useful to solve the technical contradictions are identified and they work as idea triggers, mainly helping in overcoming thinking inertia and giving way to new innovative ideas. This is how Altshuller's contradiction matrix is useful in finding inventive principles to solve technical contradictions.

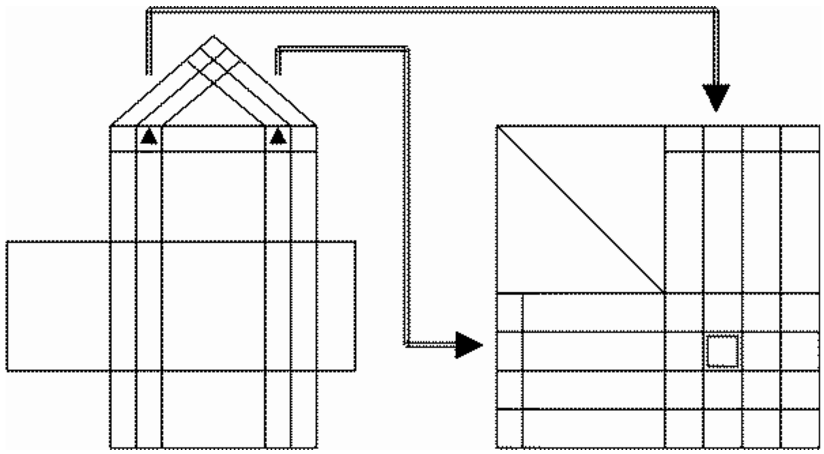


Figure 4. Simplified representation of the link between HOQ and TRIZ's contradiction matrix

In order to have the ideas properly structured, the functional tree structure, as described by Clausing [8] and Pahl and Beitz, can be used: The primary or global useful function of a system is decomposed in sub-functions at different hierarchical levels. In this case the term function is defined as the input/output relation in one technical system that has to fulfill a task. Sub-functions are, therefore, also input/output relationships that fulfill sub-tasks in the technical system. Functions are then described in terms of actions fulfilled on objects, where the actions are described by verbs and the objects by parameters or substantives: i.e., "to increase torque" "to transfer load" "to decrease rotational speed" "to cut metal", etc.
Building on the concept of function analysis, value engineering was developed by Miller [20] and later, Charles W. Bytheway, [20] developed the methodology called function analysis systems technique, or FAST, to decompose a basic function and organize it into a logic diagram called a FAST model, as shown in Figure 5.

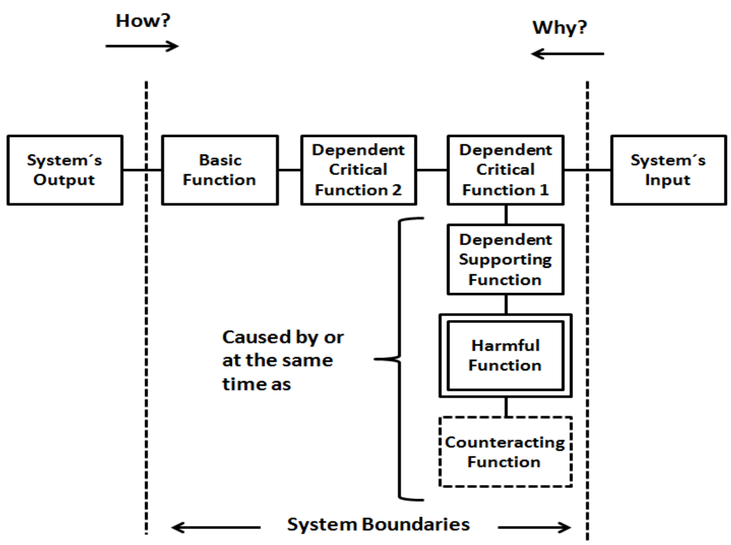


Figure 5. FAST approach to functional decomposition, as developed by Charles Bytheway in 1964

4. **Set-based Design and Evaluation of Conceptual Designs**

Set-based design is a methodology for early engineering design based on creativity, innovation and practicality (25). It is a concurrent methodology, in which a fixed design space is defined and a set of design requirements has to be met. From that, different design alternatives that would meet the specifications are explored. What makes this methodology concurrent is that these alternatives are developed in parallel and once developed, an evaluation is performed to determine which alternatives meet specifications. The choice of the best alternative is done as late as possible in the conceptual design process.

A key factor in the success of the set-based design methodology is the delay in choosing the best alternative and the reason to do this is to allow the evolution of the various proposals to a degree of simple experimental prototype in which to identify the risks inherent in each alternative. This is the main advantage of this methodology: to identify risks in early stages where change costs are minimal compared to making changes later in the design. It is very important not to admit a favorite alternative at the beginning because this could generate a decision based on unproven expectations.

In most development projects, only one option of any subsystem is created and the expectation is that all subsystems relate properly; and as a result the system is rigid (1A-2A-3A-4A). Defining subsystems at an early stage using and expecting them to function as optimal may prove to be unlikely. Implementing the SBD methodology allows parallel development of different options, subsystems A B C D, allowing for the possibility of selecting the optimal interaction between subsystems (1A-2B-3E-4A) and, thus, increasing the chances of achieving the objectives of the system.

The use of the SBD methodology generates numerous potential alternatives and these multiple alternatives involve various technical challenges. To achieve a solution to this large number of technical challenges the TRIZ methodology is used to accelerate the process of invention, thus allowing for synergy between the SBD methodology, which generates multiple alternatives and TRIZ, which provides technical support to each alternative.

5. **CAI and DFMA**

A new category of tools known as CAI (computer-aided innovation) is growing as a response to a higher industry demand. These new tools are challenging the previous standards, with the goal of supporting enterprises throughout the complete innovation process [13]. Although some initial ideas focused on assisting product designers in their creative stage, a more comprehensive vision conceives CAI as providing help up to the introduction of successful innovations in the market. New knowledge-based engineering systems support innovators' activity through rules and knowledge re-use, thus reducing the product development time while increasing its functionality, quality and reducing environmental damage.

In a lean concurrent engineering view, the phases of conceptual design, optimization and detailed design must be integrated to reduce development time (Figure 3). In this context DFMA methods, as developed by Boothroyd and Dewhurst [22] , and the corresponding software can be considered in the stage of optimization systems. DFMA supports the possibility, considered practically impossible, that manufacturing engineers and product designers can be involved at the early stages of a product’s design. This enables feedback for design engineers because it becomes conceivable to estimate the labor content of a design, including sub-assemblies and individual components that can be upfront related in both graphical and tabular form to the different costs associated with different manufacturing processes and materials, as to the time and complexity, smoothing a constructive exchange of ideas toward the goal of a realistic, competitive design.

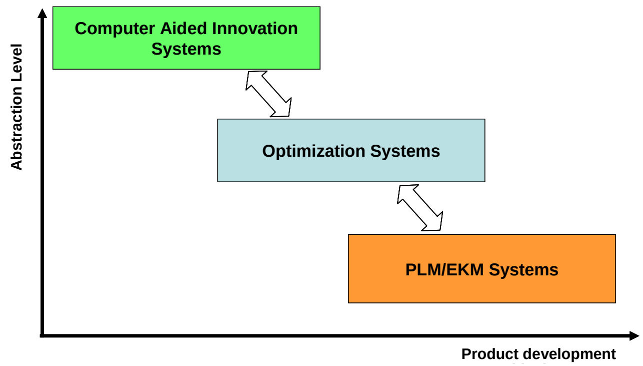
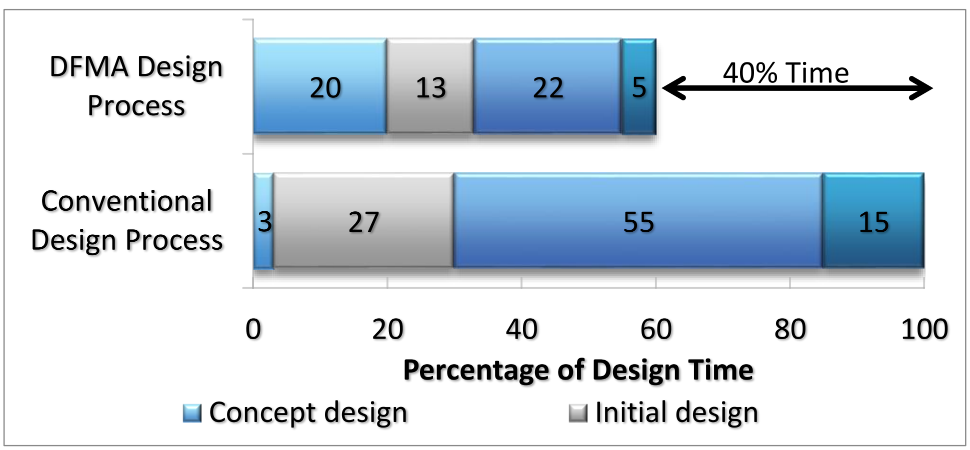


Figure 5. Methods and systems to support product development process [13]

The subsequent debates can focus on data, rather than on opinions and guesses, as understanding and quantifying the impact of alternative designs on manufacturing from the earliest stages of a product's development makes it possible to identify which solution will minimize the costs while maintaining or possibly enhancing performance. As a result, DFMA significantly contributes to the reduction in development time and product costs, as shown in Figure 6.



Courtesy of Boothroyd Dewhurst, Inc. 2015 *Source: Plastics Design Forum*

Figure 6. How DFMA shortens the design process

6. Lean Blue Innovation

Up to the point of incorporating the fuzzy front end tools, we had coined the integrated approach as "lean 3z thinking" as that integration focuses on a new way of customer-centered innovative thinking that facilitates looking for new innovative solutions that target the preferences of customers, while looking for low costs. By integrating functional analysis, set-based design and especially DFMA as part of other CAI tools guidance is provided to the design team, which helps in simplifying the product structure to reduce manufacturing and assembly costs. As DFMA is a very strong aid for eliminating waste and inefficiency and accelerating the innovation process, reducing time to market and enhancing the likelihood of success, DFMA adds new value to this integrated approach, with the expected result of achieving an innovation process that is effective and reliable. The integration of the TRIZ concept of trimming and the concept of minimum part criteria in DFA, provides the possibility of using DFA as a computer innovation tool [17]. Trimming is removing elements or replacing parts, features, or the component functions with other constituents. DFA is related to trimming in that most times you need to remove parts to make a product easier to assemble, easier to repair and more competitive. The main function of design for assembly is to help identify how to simplify the structure of the systems by minimizing the number of parts and to streamline the assembly, design and/or manufacturing processes, while the TRIZ trimming concept means that a component of a system or a process is eliminated and its useful functions transferred to other components.

The trimming decision may be made based on the three inputs:

1. Functional significance,
2. Cost and,
3. The “headache index”, which is an integral measure of complications related to operation and maintenance of the component.

In this manner, the integrated concept DFA/trimming delivers not only an optimization of existing products but also a new way for maximizing value and minimizing costs and problems.

This new integrated process may be coined “lean blue innovation”, as that integration creates a structured way for finding the blue oceans that drive the growth and development of the products that will succeed in the market due to minimized costs and maximized performance.

From the various sources, including the one mentioned before, we derive a proposal of a proprietary model that integrates the best practices identified today, around a cyclical and complete product development process. See Figure 7.

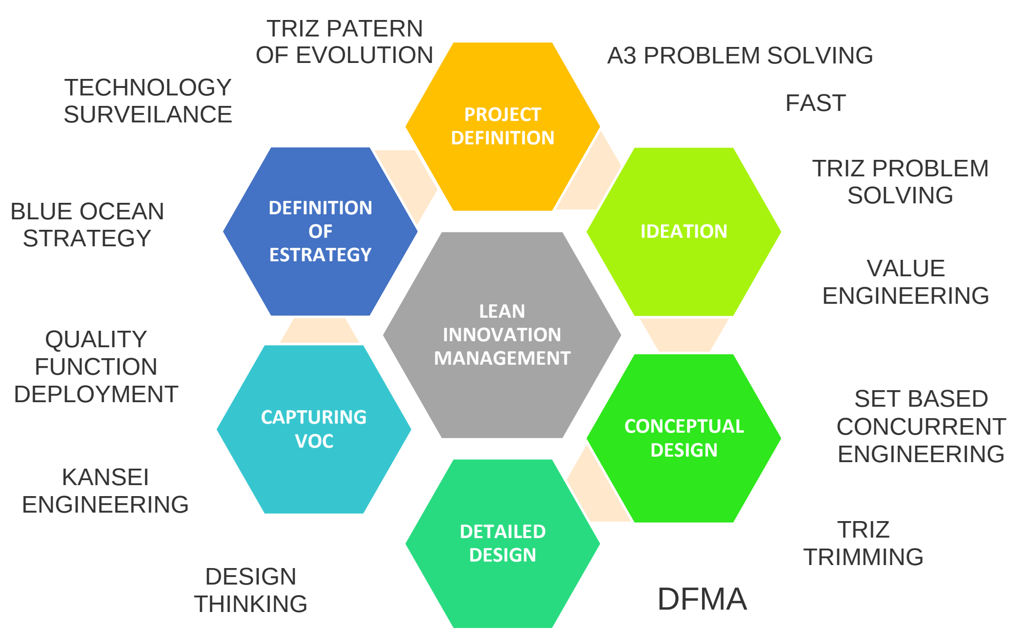


Figure 7. Proposed model of the innovation process and analyzed tools: LEAN BLUE INOVATION

8. **Conclusions**

Although a comprehensive approach for the integration has not yet been established and further work is required, several opportunities of synergy and need of improvement have been recognized and implemented that enable continuing integration of the most promising tools and methods.

We started the paper stating that the innovation process is a complex system of activities required for taking advantage of opportunities in the market. It is an information generating process, which starts with an abstract, uncertain and confused description of a new market opportunity. The integration of QFD/VOC with design thinking and Kaisen engineering helps in this process. As a second step, there is the definition of the strategy, and for creating a solid strategy we rely on methods such as blue ocean strategy (BOS), technological surveillance and TRIZ's patterns of technological evolution, all of which help to create a conceptual scenario. At the creative stage of the model we go from a definition of the actual situation in terms of the voice of the customer using QFD, including the definition of the required performance parameters and targets and go through technical and physical contradictions that are identified and several TRIZ tools to help develop inventive solutions that lead us to the conceptual scenario derived from the strategy defined. To properly structure the ideas, functional analysis is used, together with morphological analysis, and is evaluated using set-based design methods, together with value engineering, CAI and DFMA. A proposed model is derived and is the basic framework from which several case studies are being conducted at the time of the writing this paper in order to test and validate it.

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