Guillermo Cortes Robles *Editor*

TRIZ in Latin America

Case Studies

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To Andrea with all my love

Preface

This book aims to explore, even briefly, how the Theory of Inventive Problem Solving (TRIZ) is used in some countries in Latin America. The case studies included in each chapter offer a broad perspective, but this does not mean, in any way, that these cases represent all the efforts and research that several companies and universities are carrying out. It was more complicated than expected to collect the experiences reported in this book, particularly from the industrial domain. Different enterprises have assimilated the TRIZ way of thinking and integrated this knowledge into their production system. However, there is a certain reticence to share these experiences. Nevertheless, I sincerely hope that these cases will produce a different point of view on how TRIZ is being applied or adapted in different contexts.

The adoption of the Theory of Inventive Problem Solving (TRIZ) in developed countries or more mature economies is nowadays a well-explored topic. However, in the first stages of the adoption process, the interest of the academy and industry faced several obstacles, such as the lack of valuable information and the absence of experts, among other relevant deficiencies. Nevertheless, the adoption effort had paid: TRIZ is an accepted approach for problem-solving, and like any other technique, it is now following different evolution paths. However, despite the usefulness of TRIZ, in Latin America (LATAM) and other emerging economies, the adoption of TRIZ faces several difficulties:

1. The lack of a practical strategy to communicate the TRIZ concepts and purpose. Hence, the usefulness of TRIZ, its advantages, and its benefits are practically unknown.
2. The companies with a depth of TRIZ insight frequently face several financial restrictions to acquire the necessary competencies and tools for applying TRIZ. Also, the limited offer of expert training programs makes the adoption of this approach for problem-solving more complicated.
3. The lack of experts in the academic and industrial domains to translate the TRIZ philosophy to the culture of Latin American countries also contributes to slowing down TRIZ assimilation. Hence, it is necessary to propose new strategies to

incorporate the TRIZ "way of thinking" and its capacities in academic programs and as a technical resource in the industry.

4. The organizations that support scientific research sometimes are not aware of the usefulness of TRIZ to produce value. Thus, research initiatives are extremely limited or discarded due to a lack of perspective and inadequate evaluation criteria. This circumstance limits the design of more appropriate and congruent tools that better fit Latin American enterprises' needs.
5. It is possible to observe a solid industrial orientation to continuous improvement processes. This condition assumes that the market and the pace of technological evolution are stable or that they evolve predictably. The diversity of available techniques to assist continuous improvement activities, which is enormous, proves this argument. Hence, several companies dedicate a considerable effort to keep "the line moving" by assimilating available technologies. Consequently, the conditions for impelling innovation and assimilating new techniques or tools for modeling and solving inventive problems do not find their place. However, it is possible to observe that in the past two decades, the need (or even the urgency) to consolidate the innovation process as a strategy to strengthen the national industry, improve productivity, and increase the social benefits is present in the Government agendas.
6. Another relevant aspect emerges in companies focused on continual improvement: they are excellent at assimilating technology instead of developing their technical solutions. It is true that this orientation reduces risks but also inhibits the learning process. Hence, the possibility of developing new approaches, technology, or simply a more suitable solution also is affected. In Mexico, the past administration had a program to stimulate innovation, which positively impacted the Mexican industry. Therefore, it is urgent to discuss and evaluate programs' relevance to promoting innovation.
7. Considering innovation as a random output and not as a technical process does not help assimilate new techniques. It is interesting to observe that creativity is often considered a gift, not a human capacity. Hence, the technical side of creativity is not considered an additional resource for problem-solving. As a result, the innovation process is perceived solely as a kind of art without a technical component.
8. The opposition to change and use other techniques than brainstorming due to its simplicity. Simplicity is an evolution path in TRIZ. Besides, there is a complementary relationship between brainstorming and TRIZ. In this relation, brainstorming offers an open via to explore the solutions space and lets creativity follow any path. However, intending to search for valuable solutions, creative efforts need to find the "right" direction. TRIZ can propose these directions and then act as a pipeline in the problem-solving process.
9. The interaction of TRIZ with other techniques and approaches is part of its evolution process. For example, the relationship between TRIZ and Artificial Intelligence is an exciting emerging domain, to mention one field. However, the transference of the TRIZ way of thinking into other fields is probably one of the essential benefits of succeeding the TRIZ assimilation.

Despite the obstacles to the assimilation of the TRIZ technology, Latin America and other emerging economies have strong incentives to embrace change:

- The need for an approach to facilitate the development of new products or propose valuable solutions.
- An evident necessity to transform the available natural resources into valuable products or solutions. Mega-diverse countries such as Brazil, Colombia, Costa Rica, and Mexico, among several more, have enormous reserves of natural resources that must be an essential element for development. Nevertheless, this development must be guided and controlled to assure the stability and security of the next generations. This purpose asks for new approaches to propose inventive solutions without compromising the future. TRIZ has a lot to say in this context.
- The need to transform the local industry to compete internationally and solve the enormous variety of problems to reduce the environmental impact through sustainable processes and products.
- The absence or scarcity of technical and financial resources increases the urgency to change and moves society to search for new resources. Creativity and knowledge are the raw material to evolve in such restrictive conditions.

The assimilation of TRIZ has then followed different paths. This book offers a brief but relevant perspective on the more successful strategies to adapt the Theory of Inventive Problem Solving to fit the industrial and academic needs of Latin America Countries and other emerging economies.

Veracruz, Mexico Guillermo Cortes Robles

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Contents

Chapter 1
A FOS-Based Framework for Software Design Pattern Replacement

Ulises Juárez-Martínez, Julio-Andrés Beverido-Castellanos, Erika-Auryly García-Cantú, and Karen Cortés-Verdín

Abstract The solution to recurring problems in software has been solved with design patterns, which are considered modular units that are feasible to be encapsulated and reused both in code and in implementation. In the context of reuse and considering the intention of the pattern, the replacement of design patterns is feasible, although the modular properties behind the design pattern depend on the designer's experience. To facilitate the replacement of software patterns systematically, the authors propose a framework based on Function-Oriented Search (FOS). FOS is a TRIZ-based tool that facilitates the transfer of knowledge between areas. The framework uses a simplification of the FOS algorithm for its use in the context of software and for supporting expert designers in solving recurring problems with other patterns as alternatives. The goal of this work is to demonstrate the feasibility of replacement between patterns using functions identified from the Gamma templates (Gamma et al. 1995) and the classification proposed by Metsker (2002). To complement this new design perspective and to specify the basis of replacement, this work considers the structural similarities of the patterns. Based on the common functions between patterns, it is possible to obtain the versatility and adaptability of each design pattern to determine the replacement potential.

Keywords FOS · TRIZ · Software design patterns · Java · AOP

1.1 Introduction

Given the software industry needs, systems are improving and constantly evolving; therefore, having good design and code-level practices is essential to produce long-term software which satisfies user needs. Design patterns (Gamma et al. 1995) are

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proven solutions for recurring software problems. Patterns are applied based on their intention to offer reusable software elements at the design and code levels. Considering the previous statement, pattern replacement is doable. However, this kind of replacement has been reported to have been done only based on the pattern intention considering neither interfaces nor a design principle. In many cases, pattern replacement is done depending on the designer's experience, complicating true modularity, and software architecture evolution.

As a solution to the problem, TRIZ theory (Theory of Inventive Problem Solving) offers tools such as Function-Oriented Search (FOS) (Litvin 2005) and inventive principles for the non-conventional problem's solution. FOS methodology, by the identification of a critical issue and functions, allows an expert to search for technology for knowledge transference solving, therefore, the initial issue. Also, inventive principles propose contradiction solving and offer resolutions for non-conventional issues.

This work aims to demonstrate the feasibility of design pattern replacement considering the derived functions obtained from the templates proposed by Gamma et al. (1995) and from the classification proposed by Metsker (2002). Furthermore, the work considers analogies between design patterns and TRIZ's inventive principles (Rea 2001a, b), in such a way that the new software design perspective offers pattern replacement feasibility.

Given that the context of the problematic implies working with TRIZ's inventive principle analogies between design patterns and with pre-established technologies (objects, aspects), some steps of the FOS methodology could not be applied; therefore, an adaptation was made justifying the selection of the steps. Moreover, based on the functions obtained from the pattern templates, tables of functions were generated related to each design pattern to identify similarities between them, thereby defining a framework to identify and apply the replacement potential. Based on the stated, a pattern that shares more functions with other patterns increases its feasibility of replacement. Furthermore, a pattern that replaces several different patterns is considered versatile and, a pattern that can be replaced by different patterns is deemed to be adaptable.

The structure of the paper is as follows. Section 1.2 deals with the most relevant state of the art related to suggestions for the replacement of design patterns as well as proposals for using TRIZ/FOS in software design. Section 1.3 presents the modified FOS algorithm for the replacement of design patterns. Section 1.4 details the proposed framework to identify and apply functions derived from design patterns, showing how to obtain complementary functions from synonyms. It also presented how the structural similarity complements the substitution, as well as the way of testing after applying substitutions. Section 1.5 describes the results obtained, emphasizing the generation of function-by-function matrices and observing the degree of adaptability and versatility of design patterns; this section also presents the study case, showing the application of the FOS steps in the modification of the framework for JUnit software tests, as well as the codes generated to make the replacements and their respective tests. Finally, Sect. 1.6 presents the conclusions and future work.

1.2 State of the Art

This section shows the most relevant works on pattern substitution in software design, including architecture and evolution, as well as the reported works of TRIZ and FOS applied to software design.

1.2.1 Software Design Domain

Due to the importance of standards to build high-quality software (Buschmann et al. 2007), the integration of design patterns into the software architecture is discussed. From the perspective of non-functional properties, design patterns allow us to satisfy non-functional aspects such as changeability, interoperability, efficiency, reliability, testability, and reusability. Concerning changeability, it is vital that the architecture is prepared for modification and evolution. Changeability considers maintenance, extensibility, refactoring, and portability. Specifically, extensibility focuses on software extension by new features as well as the replacement of components with improved versions, and even the removal of unwanted components. Patterns like Adapter, Bridge, and Reflection play a significant role in the replacement and integration of new components. A software system designed to support change also supports variability, a desirable feature to satisfy different customers. The Bridge pattern by separating the interface from the implementation allows changing implementations that can be represented by other design patterns.

Patterns literature (Mens and Tourwe 2004) frequently reports the use of two or more patterns for essentially solving the same kind of problem. For example, the Strategy and Template Method patterns solve issues of variability in the sequence of steps an algorithm follows. Active Object Monitor Object patterns allow the coordination of shared objects in a program. The Half-Sync/Half-Async and Leader/Followers patterns allow concurrent processing of requests. The Builder, Prototype, and Abstract Factory patterns create objects handled similarly, and finally, the Adapter pattern has always been reported as a single pattern that offers two types of solutions: a class level and another at the object level (potentially interchangeable solutions). All these patterns are examples of pattern competition, and each group of competing patterns is a group of replacement patterns.

Software refactoring designed with design patterns (Jahnke and Zündorf 1997) is an activity that aims to identify design patterns poorly implemented and improve quality without affecting external behavior. In Bouhours et al. (2009), is stated that design pattern replacement is useful in software maintenance activities. Poor implementations are feasible to change for higher quality implementations. A generic network fuzzy reasoning was used in this study to identify low-quality applications, and semi-automated support-assisted pattern substitution. A system generated the tests that carelessly implemented the Singleton pattern; the fuzzy reasoning was used to get areas of replacement (segments of design that are necessary to ensure the correct replacement of design patterns). The results show that maintaining code with this approach isolates the system of side-effects due to maintenance.

Gamma et al. (1995) considers design patterns as architectural building blocks because they represent models with successful abstractions. So, the authors propose an approach based on design patterns for software development and evolution. With this approach, the requirements are implemented directly by one or more design patterns that provide locality and traceability. Therefore, a change in software requirements impacts specific parts of the architecture and allows implementing new patterns as needed. On the other hand, the replacement of the current patterns representing the original requirements achieves software evolution, and for different patterns it represents the implementation of new requirements. Regarding traceability, it allows for a direct mapping from requirements to design models, design patterns, therefore, are relevant to document reuse and software evolution the authors show how the Observer pattern is replaceable by the Mediator pattern, and the Iterator pattern is replaceable by the Memento pattern. The proposed model makes the necessary adjustments considering adaptable interfaces, relationships between patterns, and pattern relationships with the rest of the design.

In Bouhours et al. (2009), the authors mention that design patterns offer advantages of genericity, reusability, and inerrability. Such advantages provide essential properties in model-driven processes that allow for the reuse of knowledge using patterns. Furthermore, patterns become independent business models which are, therefore, not necessarily planned. Under these conditions, software architecture should enable a designer to integrate design patterns at any time. Besides, the ability to identify inappropriate designs to be replaced by designing patterns offers better design and promotes architectural quality. As a case study, a system was used to replace poor design segments to obtain a better design. To achieve this, after the design phase, some review activities were proposed to determine design fragments performing similar activities. With automated help, the model was analyzed to identify design fragments like bad design practices stored in a knowledge base. Validation is performed interactively by the designer, and then he/she proceeds to a refactoring process. In this way, the designer doesn't need to identify a design problem. Identification capabilities are based on an ontology that formalizes the corresponding design pattern considering intentions and relations with other patterns. This work finds a design pattern as a reusable optimal micro-architecture for a problem. The case study examined only the Composite pattern.

In distributed computing specifically, interoperability mechanisms are also desirable replacement capabilities for components and design patterns. In Buschmann and Henney (2007), thirteen GoF patterns are mentioned as beneficial to support adaptation and extension. For example, Bridge and Adapter patterns play a central role in component and pattern replacement; however, it is helpful to exchange these patterns to address specific adaptation needs. Chain of Responsibility and Interpreter patterns are suitable to substitute similar patterns to separate interface from implementation, as is the case of Adapter, Composite, and Visitor patterns. The Interceptor pattern allows the exchange between interface patterns (like Adapter) with the Observer pattern for the administration of invocations. In the case of extension, it is desirable to exchange between Visitor and Decorator patterns to ensure explicit interfaces and double dispatch. Finally, for variations of behavior, several patterns are replaceable by essentially two patterns: Template Method and Strategy. From the perspective of resource management patterns like Object Manager, Container and Component Configurator create a synergy for an infrastructure that enables component replacement and redeployment. Container pattern is a substitute for Reflection, Broker, and Microkernel patterns.

The composition between design patterns arises when some classes are shared or when there are common method calls. This composition ability allows for developing better architectural blocks to allow for the implementation of more robust solutions to recurrent problems. In Bača and Vranić (2011), it is studied how to replace object-oriented (OO) design patterns through aspect-oriented (AO) design patterns. The goal is to obtain better composition regardless of the type of design pattern. The proposal arises from the observation that AO languages are extensions of OO languages; OO patterns are directly applicable in the context of aspects. Intrinsic AO design patterns such as Worker Object Creation and Cuckoo's Egg present a better separation of concerns and composition since their implementation is in a simple aspect matter without affecting other OO design patterns at the code level. The work presents a set of tests that shows the capability of intrinsic AO design patterns to replace some AO re-implementations of OO design patterns. Finally, results improved using a quantitative assessment comparing intrinsic AO design patterns with AO re-implementations.

1.2.2 TRIZ/FOS Domain

Theory of Inventive Problem Solving (TRIZ) offers alternatives to solve problems characterized by contradictions. In the context of software, these contradictions can be found in the design and implementation of non-functional requirements. TRIZ provides 40 principles that provide insight into the solutions most commonly used to eliminate contradictions. In this sense, design patterns are considered instances of the 40 inventive principles behind the observation that both approaches are based on a set of heuristics to provide solutions to recurring problems. In Stamey and Domb (2006), the authors report seven analogies between inventive principles and design patterns:

- Adapter and principle 24—Mediator.
- Bridge and principle 2—Extraction.
- Composite and Iterator with principle 6—Universality.
- Decorator is associated with principles 7 and 30—Nesting and Flexible Membranes.
- Facade and principle 5—Consolidation.
- Flyweight and principle 17—Transition into a New Dimension.
- Proxy with principles 35 and 36—Parameter Changes and Phase Transition.

Although the authors are TRIZ experts, there exists certain complexity in finding analogies between TRIZ and software concepts. Even when only the structural patterns were analyzed, the work mentions the intention to complete the 23 GoF catalog patterns. However, no work suggests that this area of interest has been covered. This document is one of the first to relate TRIZ to design patterns, although the idea of using TRIZ in software emerged several years ago.

The object-oriented design aims to accommodate properly non-functional system features. However, the relationships between objects impose constraints for the proper implementation of such properties. In that sense, design patterns offer an alternative solution to reduce the dependence among objects, i.e., it can minimize coupling. This type of conflict is addressed in Jianhong et al. (2009) using analogies of the TRIZ contradiction matrix, but specifically for OO design patterns. The authors identify the improvement parameters of the TRIZ contradictions matrix in design patterns by analyzing interfaces, classes, and objects and then building the contradictions matrix. From the matrix, a design plan is established to guide the design and design improvement. The results suggest that the elimination of contradictions involves the possibility of exchanging implementations (possible solutions), so the replacement of design patterns is a necessity. This work provides guidelines for applying TRIZ in object-oriented analysis and design from design patterns analysis. However, it does not relate the TRIZ inventive principles to pattern features but instead provides a contradiction matrix like the TRIZ contradiction matrix to solve OOD problems.

Similarly, Beltrán et al. (2011) proposes an approach for combining TRIZ inventive principles with software design patterns. The aim is to probe substitutability among design patterns and encourage reuse. Beltran analyzes the 23 GoF design patterns and the eight most significant patterns of the Aspect-Oriented Programming (AOP) paradigm. To achieve this objective, each TRIZ inventive principle and design pattern was carefully analyzed to create correspondences with software development. Therefore, it is possible to establish a relationship between software development problems and frequently inventive principles that solve them. A relationship between the inventive principles and suggestions for good design was also determined. As design patterns are related to each other depending on the characteristics they have among them, establishing the relationships was possible. The paper takes two approaches: on the one hand, the use of inventive principles related to design patterns to find out which patterns are associated with each other and why, and, on the other hand, the use of design patterns to find out which principles are related to each pattern, so patterns with the same principles were identified. Likewise, similarities were found that allow pattern substitution using inventive principles. The work also provides a basis to determine which design pattern is suitable to use according to principles and suggestions obtained from TRIZ.

In Rea (2001a, b), the authors express the lack of a systematic approach that supports the use of design patterns, leaving for the designer's experience, major design decisions. The solution to the problem proposes the recognition of the 40 principles of the TRIZ contradiction matrix in the intent of the design patterns. The results generated a table that allows observing what inventive principles are present for each design pattern. The structural patterns are more capable of association with inventive principles, followed by behavioral patterns and finally, instantiation patterns. Observing the coincidence of principles among various patterns, several controlled experiments were done to assess the possibility of replacing patterns and respond to the feasibility of using a design pattern as an alternative solution to a contradiction in the design. The results show that inventive principles as reusable strategies play an important role in suggesting a guide to solve a problem. Analyzing the correspondence between inventive principles and design patterns generates a systematic way to implement these patterns to guide the more proper pattern selection according to the applied inventive principle.

In Rea (2001a, b, 2006), Fulbright (2004), 40 TRIZ principles are addressed in the context of software. The authors propose a methodology to solve problems in software and information technologies. Each principle relates to specific cases of analogies in software along with proposed examples to understand how to solve problems. However, design patterns are not mentioned. As a result of these works, in Mann (2004), an actual case is offered by applying TRIZ using only two principles: Mediator (24) and Copying (26).

In Van Den Tillaart (2006), the author expresses that there are some gaps in the work of Rea (2001a, b) and proposes to adjust it by using software analogies and different examples from those proposed in Rea (2001a, b) so that they can be easily compared and understood by readers. Examples in the essay include areas such as design level, and in some cases, an implementation level. Van Den Tillaart (2006) proposes separating analogies according to the different stages of the software life cycle: requirements definition, analysis, architecture design, development, deployment, and maintenance process. The author includes an analogy not involved in Rea's work: the inventive principle 39—inert atmosphere. This document and (Fulbright 2004) provide analogies to principles 31, 36, 37, 38, and 39, taken in addition to Rea's work.

In Mann (2015), it is stated that software is radically different from mechanical systems. However, the use of TRIZ is feasible. The work discusses the TRIZ principles from the software perspective: idealism, emergency, functionality, resources, interface/space/time, and recursion. It explains the law of system completeness involving control cycles and machine tool transmission, the latter being one of the two substances in the substance field model. Also, the work mentions distinctly the patents for using TRIZ in software like networks and real-time systems. Moreover, it describes the frequency of use of each of the principles in software and a comparison between the TRIZ matrix and the software matrix. Finally, (Wang et al. 2001) presents a real case study solved with TRIZ for the aerospace industry: remote-controlled crewless air vehicles (UAVs).

In Houston (2017), TRIZ inventive principles are used to achieve a process commonality in architectural design. Process commonality presents a contradiction between the project managers, who demand a common process in software development to improve resources. TRIZ principles are used considering two approaches: the 39 TRIZ engineering parameters and the Ruchti and Livotov approach. A comparison was made using the TRIZ engineering parameters to generate a contradiction matrix, the inventive principles considered were number one and number 35, and Homogeneity-Diversity, Standardization-Specialization for the Ruchti and Livotov approach. The work presents a series of tests formulating some questions using inventive principles to determine a positive impact on architectural design and gives some examples from the literature.

Considering evolution patterns in the IT industry, (Govindarajan et al. 2019) cites TRIZ research which shows the IT trends that can be followed by the software industry to achieve ideal solutions; such trends are.

- Controllability Trend—software with predictive capabilities.
- Reducing Human Involvement Trend—as the trend suggests, humans start to become less critical in software development.
- Customer Intangibles Trend—software capable of carrying out the client's real needs.
- Nesting (Up) Trend—software production without knowing how to code.
- Design for Robustness Trend—software evolves to become more "error-proof".
- Trimming Tread—extra software will be removed, keeping only systems that can deliver all intended capabilities.
- Customer Expectation Trend—the software industry will shift from "service" to "experience".
- Design Point Trend—software will have adaptable algorithms.
- Knowledge Trend—software will be able to sense and adapt to new contexts.

In Pérez et al. (2012), a process to analyze and solve inventive problems in Software Systems based on the contradiction matrix is proposed. The solving process is described via an antivirus system case study. The solving process involves four stages: (1) identifying the problem, (2) representing the problem by a technical contradiction, (3) finding inventive principles, and thus (4) finding the specific solution. The results confirm that the suggested inventive principles are a powerful tool for creative problem-solving in software systems, in which the solution space is broad. Therefore, the analysis and use of this TRIZ tool in more cases are recommended. It is also important to note that principles are not a universal problem-solving method, but a paradigm that requires being correctly adapted to the problem to solve.

Several additional works applying TRIZ are reported: Quality problems in software (Wang et al. 2001), quality of the object model (Goyal et al. 2012), modeling features of software products by Goldfire Innovator tool (Stanbrook 2002), defining a Design for Excellence Framework using TRIZ principles (Brad 2021), the feasibility of solving problems faster using TRIZ methodology and simultaneous analysis by specialists (Cho 2020), and resolving contradictions in software architectures (Kluender 2022). As can be seen, only efforts from (Stamey and Domb 2006; Jianhong et al. 2009; Beltrán et al. 2012) have considered TRIZ with design patterns.

Since the adoption of TRIZ can present itself as a contradiction, (Litvin 2005) proposes a new approach to solving this obstacle. As mentioned in the introduction, Function-Oriented Search (FOS) is a methodology that eliminates inconsistencies and allows the resulting solution to be an existing technology, enabling the transfer of the solution from other contexts.

Letvin (Simon Litvin and Feygenson 2010) mentions the relevance of the function approach for analyzing engineering systems at the design level to formulate and solve inconsistencies. Furthermore, Montecchi and Russo (2015) describes a semantic approach for FOS considering a patent searching framework; the work presents a procedure for Technology Transfer (Solution Transfer) using a method for information retrieval. Also, Sungchul Choi et al. (2012) offer a function-oriented database (Function-based Technology Database—FTDB), which is a repository of technical information represented as a function. In this work is applied an FTDB by a Subject-Action-Object (SAO) patent model based on functions. This approach uses modeling ontology fact-oriented SAO structures extracted from patent documents and implemented in FTDB (a system to support FOS). The proposed method facilitates patent recovery; therefore, it gives a better FOS analysis and knowledge transference. As noted in previous works, function-based procedures allow for knowledge transference, facilitating the analysis and solution of a problem. Such procedures are a valuable opportunity area in the software engineering domain.

Gräbe (2021) mentions the relevance of detailing a technical system but considering the system itself as a whole. The approach of detailing a system is relevant to have adaptable and versatile systems. On the other hand, (Kneer et al. 2021) study systems development using adaptable strategies which can be useful in the early phases of software development.

1.3 FOS Algorithm for Design Pattern Replacement Proposal

The search for solutions in areas other than the original problem is a repetitive activity. Nevertheless, the probability of finding a solution is low because the search domain becomes too extensive to dimension it properly. In the case of finding a solution, the problem cannot be solved due to the lack of knowledge. The Function-Oriented Search offers an algorithm that allows the transfer of knowledge between areas. The algorithm is described as follows (Litvin 2005):

1. Identify the critical problem that inhibits the solution of the initial problem.
2. Formulate the necessary functions to solve the critical problem.
3. Formulate the required functional parameters.
4. Formulate a general function.
5. Identify the leader areas of industry in which this type of function is relevant.
6. Find the best experts in the identified leader areas.
7. Based on professional databases and the knowledge of the experts, identify the candidate technologies.
8. Select the closest technologies to the required functional parameters.
9. Formulate a secondary problem that potentially inhibits the immediate implementation of the selected technology to solve the problem.
10. Solve the secondary problem.

11. Describe an existing technology slightly modified as the solution to the initial problem.
12. Manage the necessary data with the identified technology to suggest a practical implementation plan.

The application of the FOS algorithm in the context of software requires considering only the necessary steps; this is due to the virtual nature of software, which possesses properties different from the ones found in physical and chemical processes. Table 1.1 shows the reason why some steps in the algorithm are considered for design pattern replacement.

Considering the above, the adaptation of FOS selects steps 1, 2, 3, 4, 6, and 12 from the original algorithm:

1. The critical problem is generic—replace a design pattern with another maintaining the same results.
2. The functions are defined from the intention of the design patterns, and the Applicability and Consequences sections from Gamma's template (Gamma et al. 1995) and Metsker's classification (Metsker 2002).
3. The parameters are the ones specified by the objects in the design pattern.
4. Based on the identified functions, formulate a general function that allows the replacement of design patterns considering the matching functions of the patterns.
5. Find the best experts in the identified leader areas: Both FOS experts and TRIZ experts are required to facilitate the association of inventive principles with design patterns and with the function recognition process.
6. Manage the necessary data with the identified technology (identifying the replaceable objects and selecting the core parts of the design pattern with abstract aspects) to suggest a practical implementation plan.

Table 1.1 FOS algorithm steps applicable in design pattern replacement

FOS step	Selection
1	Yes, due to the apparent definition of a problem
2	Yes, due to the naturality of recognizing functions
3	Yes, due to the equivalency of functional parameters with method parameters
4	Yes, because it is feasible the definition of a general function
5	No, since those analogies are made between design patterns
6	Yes, considering TRIZ and software experts
7	No, because the identified technology is in the same context for design patterns
8	No, due to the same reason as Step 7
9	No, due to the same reason as Step 7
10	No, because Step 9 is not applied
11	No, due to the same reason as Step 7
12	Yes, due to the specification for software implementation

1.4 The Framework to Identify Functions in Design Patterns

This section describes the process to identify functions within design patterns, which in turn references step two of the adapted FOS algorithm. Design patterns are applied based on the intention or the problem they solve, even though they facilitate a basis to identify functions; such elements are not enough to identify functions accurately. The identification of functions was made using a detailed review of each design pattern template, and the descriptions of their classifications. The most important question to ask is how to identify a function. According to WordNet's lexical dictionary (Miller 1995; WordNet 2010), a function is (1) a purpose, role, or use for something, or (2) the actions and required activities, assigned or expected of something. Such definitions of functions were taken into account to identify functions.

To recognize functions, a framework for function recognition is proposed which considers design pattern intentions, according to Gamma's et al. (1995) and Metsker's (2002) classifications. Likewise, since intentions are not enough, also the Applicability and Consequences sections were considered, which answer a series of questions that allow the recognition of functions. Such sections are described as follows:

- Applicability: This section answers the following questions: What are the situations in which the design pattern can be applied? What are the examples of poor designs that the pattern can address? How can you recognize these situations?
- Consequences: This section answers the following questions: How does the pattern support its objectives? What are the trade-offs and results of using the pattern? What aspect of system structure does it let you vary independently?

The following example will be used as a guide to explain the procedure made for the recognition of functions and assessment of the replacement capabilities in design patterns. According to Gamma et al. (1995), Abstract Factory design pattern associates automatically with the function "fabricate". The Applicability section describes that such a pattern must be used when "a system should be independent of the creation, composition, and representation of its parts", or when "a system should be configured with one of its multiple product families". Consequently, the identified functions are "provide" and "configure". Also, the Consequences section describes that such a pattern "isolates concrete classes", "makes feasible the exchange of product families", and "promotes consistency between products". The identified functions are "isolate", "exchange", and "promote".

Based on the previous process, considering the entire template, as well as Metsker's descriptions (Metsker 2002), it is possible to create an initial table of functions. Table 1.2 shows the initial functions of the Abstract Factory design pattern.

Table 1.2 Identified initial functions for abstract factory

Pattern	Initial function
Abstract factory	Provide, configure, isolate, exchange, promote

Based on each design pattern function, it can be argued that design pattern replacement is feasible if the functions recognized between patterns are the same. Furthermore, feasibility will increase if the design patterns have more functions in common.

To facilitate the recognition of equal or similar functions between design patterns, a synonym search for the functions was done according to the functional context of the pattern. In other words, some of the recognized words are linguistically correct as synonyms, but not all of the words describe the characteristics or properties of the pattern. Therefore, a synonym search was done for each one of the identified words of functions.

To identify groups of words that refer to the same functionality, and to define, therefore, a potential replacement between design patterns, a word is considered if its description has an association with other words that are not necessarily synonyms.

The word Isolate is considered an example to identify synonyms; Fig. 1.1 shows a WordNet search grouped by similarity.

After analyzing the definition of the word Isolate, the words "Separate" and "Classify" were considered based on meanings 1 and 4 related to synonymy and description. The discarded words represent different contexts or senses from the word Isolate.

Table 1.3 shows the identified synonyms for the Abstract Factory design pattern.

Sense 1
isolate, insulate -- (place or set apart; "They isolated the political prisoners from the other inmates")
=> discriminate, separate, single out -- (treat differently on the basis of sex or race)

Sense 2
isolate -- (obtain in pure form; "The chemist managed to isolate the compound")
=> get, acquire -- (come into the possession of something concrete or abstract; "She got a lot of paintings from her uncle"; "They acquired a new pet"; "Get your results the next day"; "Get permission to take a few days off from work")

Sense 3
sequester, sequestrate, keep apart, set apart, isolate -- (set apart from others; "The dentist sequesters the tooth he is working on")
=> separate, disunite, divide, part -- (force, take, or pull apart; "He separated the fighting children"; "Moses parted the Red Sea")

Sense 4
isolate -- (separate (experiences) from the emotions relating to them)
=> classify, class, sort, assort, sort out, separate -- (arrange or order by classes or categories; "How would you classify these pottery shards--are they prehistoric?")

Fig. 1.1 Synonyms related to the word Isolate

Table 1.3 Synonyms of functions for abstract factory

Pattern	Synonyms
Abstract factory	Configure—Assemble Exchange—Replace Promote—Change Isolate—Separate, classify Unite—Combine

1.4.1 Creation of Function Tables

Afterward, to identify how many patterns shared the function (including synonyms) was determined the number of matching patterns. The functions were ordered from the highest to the lowest quantity of matching patterns, the highest number being the representative function. Table 1.4 shows a fragment of the ordered functions involving the Abstract Factory design pattern. The match between functions with other patterns is also shown.

Table 1.4 Table of functions related to abstract factory

Function	Pattern
Isolate	Abstract factory Builder Bridge Command Mediator Strategy
Decouple (from Separate)	Bridge Facade Chain of responsibility Command Mediator
Combine (from unite)	Abstract factory Composite Decorator Interpreter Visitor
Select (from isolate)	Chain of responsibility Command Strategy
Simplify (from change)	Façade Mediator Template method
Separate (from change, isolate)	Bridge Mediator
Classify (from separate)	Abstract factory
Synthesize (from change)	Template method

Table 1.5 Table of synonyms related to combine

Palabra	Abstract factory	Composite	Decorator	Interpreter	Visitor
Combine	✓	✓	✓	✓	✓
Unite	✓	✓	✓	✓	
Compose	✓	✓		✓	
Add			✓		✓

The previous process was performed for each one of the design patterns considering all the recognized functions.

Isolate has six shared patterns, which represent the most significant group. The first synonym is Decouple and has five patterns: Bridge, Façade, Chain of Responsibility, Command, and Mediator. Then, the next synonym is Select and has three patterns: Chain of Responsibility, Command, and Strategy. And so on, each synonym is ordered from the highest to the lowest number of patterns. Such predominance describes that the cited patterns are potentially replaceable among them, which is demonstrated in Sect. 1.6.

Furthermore, Table 1.5 presents a group of words with the same meaning. The "Combine" word is a representative verb since it has the most significant number of matching patterns, and also, it is a synonym of Unite (a function of Abstract Factory); therefore, it is considered a function of Abstract Factory.

Considering the group of words mentioned in the previous table, the word Combine has synonymy with the words Unite, Compose, and Add. The word Combine was identified with the patterns Abstract Factory, Composite, Decorator, Interpreter, and Visitor. The word Unite has Abstract Factory, Composite, Decorator, and Interpreter as matching patterns. Also, the word Compose has the patterns Abstract Factory, Composite, and Interpreter. Finally, the word Add has the patterns Decorator and Visitor.

Therefore, four groups were identified in which intersections determine a replacement potential between patterns related to the same function. The group with the highest word match was called the "representative pattern group".

1.4.2 Comparison of Design Pattern Structures

Looking at the structures defining each of the design patterns related to the "Isolate" function, two characteristics were identified in most cases:

- There exists an aggregation or composition association, or use relationship, necessary to use at least one type of hierarchy to achieve the goal or intention of the pattern.

- It contemplates a client (administrator, context, director, mediator, etc.) that can access the type of hierarchy. In the case of the Façade pattern, it depends on the structure of the isolated classes.

Furthermore, Figs. 1.2 and 1.3 show two design patterns related to the function Isolate: Abstract Factory and Mediator. Such diagrams have similar structures considering the isolated type of hierarchy, and they also have a client that can access such a type of hierarchy using an aggregation, composition, or use. Thus, the function Isolate is identified.

Such structural similarities define a new way to contemplate the patterns in the solution of recurring problems offering implementation alternatives. Even though it is challenging for the conventional scheme of design patterns, at the same time, it is appropriate for software architecture.

Architectural techniques define a way to satisfy the measure of a quality attribute, manipulating some aspects of the quality model using architectural decisions (Bachmann et al. 2003). In other words, architectural decisions control the parameters of the quality model to produce an expected response measure. Therefore, design pattern replacement is a way to offer design alternatives to obtain an expected response (Mirakhorli et al. 2012).

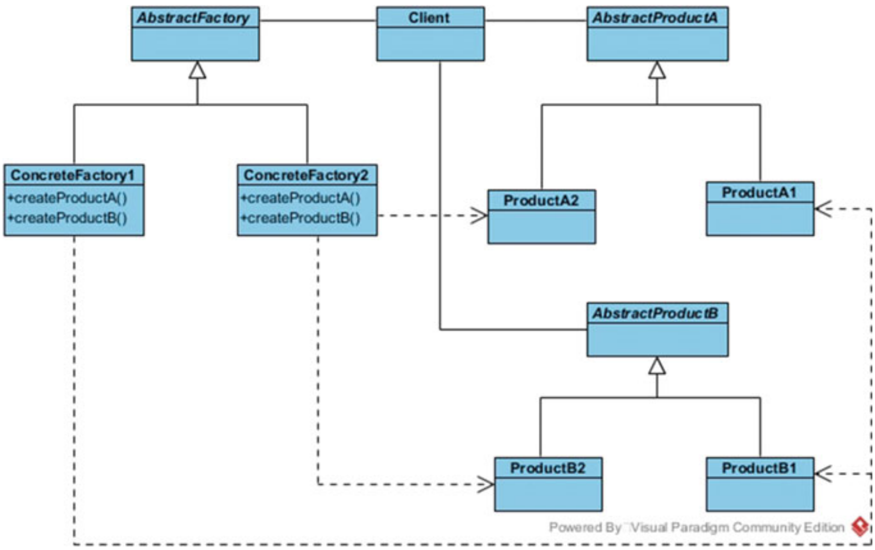

Fig. 1.2 Structure of the design pattern abstract factory

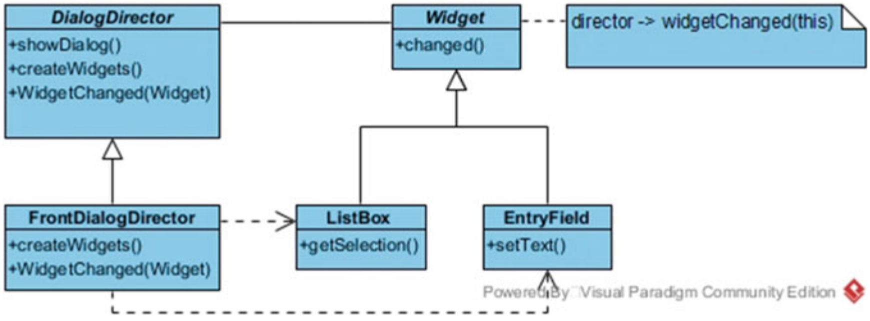

Fig. 1.3 Structure of the design pattern mediator

1.4.3 Testing for Pattern Replacement

Considering the identified functions for each one of the design patterns and their replacement suggestions, it is necessary to design replacement tests. The next steps show the created method to ensure that all the designed replacement tests are consistent and capable of being duplicated:

1. Select the pattern to replace. This pattern is named Base Pattern.
2. Perform a design pattern analysis. The class structures and their associations with the surrounding classes to identify the message exchange are considered. The message exchange is essential to determine the level of adaptation at the time of replacement.
3. Identify the core parts of the pattern.
4. Create an abstract aspect that contains cuts within the core parts of the pattern.
5. Select the pattern which is going to replace the Base Pattern. Repeat steps 2 and 3 for this pattern.
6. Invoke replaceable pattern functionality in a concrete aspect.
7. Use Introductions when required, for example: to adapt the hierarchy with `declare parents` or create the necessary methods such as getters and setters.
8. In the case of having other aspects, deactivate them to avoid interference with the current aspect.
9. Analyze the complexity of the oriented aspect solution.
10. Determine if the substitution is acceptable or not.

Given the steps mentioned above, the adaptations required to verify the feasibility of replacement between design patterns are specific cases that are not reusable. Nevertheless, the process was necessary to verify the substitution capability, and to ensure application functionality. In this way, test tools supporting aspects, design patterns, and reflection mechanisms are required.

1.5 Experimental Results

This section presents the results obtained for the construction of function-by-function matrices to identify the versatility and adaptability of patterns, as well as the application of the proposed framework in a case study.

1.5.1 Function-by-Function Matrix

Based on the data obtained from the method already described, Table 1.6 shows replacement results for the Abstract Factory design pattern. The following patterns correspond to the identified functions shown in Table 1.4, and each successful replacement is presented with a one and otherwise with zero. To present the data in a readable way, patterns were listed according to the following correspondence:

A. Abstract Factory
B. Builder
C. Bridge
D. Facade
E. Chain of responsibility
F. Command
G. Mediator
H. Strategy
I. Template method.

Table 1.6 Function *x* function matrix for abstract factory

	A	B	C	D	E	F	G	H	I
A		0	1	0	0	0	0	1	0
B	1		1	0	0	0	0	1	1
C	1	1		0	1	0	0	1	0
D	0	0	0		0	0	0	0	0
E	0	0	0	0		0	0	0	0
F	1	0	1	0	0		1	1	0
G	0	0	0	0	1	1		0	0
H	1	1	1	1	1	0	0		0
I	0	1	1	0	0	0	0	0	

1.5.2 Versatility and Adaptability

The Function x Function matrix shows the versatility and adaptability of each design pattern. The rows of the matrix represent the versatility of each pattern; in other words, how many patterns can be replaced by a design pattern. Also, the columns in the matrix represent the adaptability of the pattern (how many patterns can replace the design pattern). Thus, it is observable that patterns present hierarchies susceptible to being versatile or adaptable. The results obtained in the matrix allow us not only to identify the replacement feasibility between design patterns but also, according to the architecture of a system, to identify a possible modification point for pattern replacement.

As an example of versatility, the Strategy pattern (H row) was considered; such a pattern can be replaced, with more or less adaptation difficulty, with Abstract Factory (A), Builder (B), Bridge (C), Façade (D), and Chain of responsibility (E) patterns. From a structural point of view, these patterns have hierarchy similarities, share responsibility characteristics, and solve interface issues. A software system implementing such patterns could use the Strategy (H) design pattern to replace them.

Considering Strategy (H column) pattern adaptability, a software system implementing such a pattern could replace it with at least four patterns: Abstract Factory (A), Builder (B), Bridge (C), and Command (F). Like versatility, these patterns share characteristics, and additionally, the Command (F) pattern offers solutions in the operational matter (behavior) of the system.

Figure 1.4 shows all the cases of versatility and adaptability presented in Table 1.6. The arrows which come out of a pattern indicate versatility; otherwise, if the arrows enter a pattern, they represent adaptability. Taking the Strategy example, in Fig. 1.4, it can be noted that the H node has exits (versatility) to the A, B, C, D, and E nodes, while it has as entries (adaptability) the A, B, C, and F nodes.

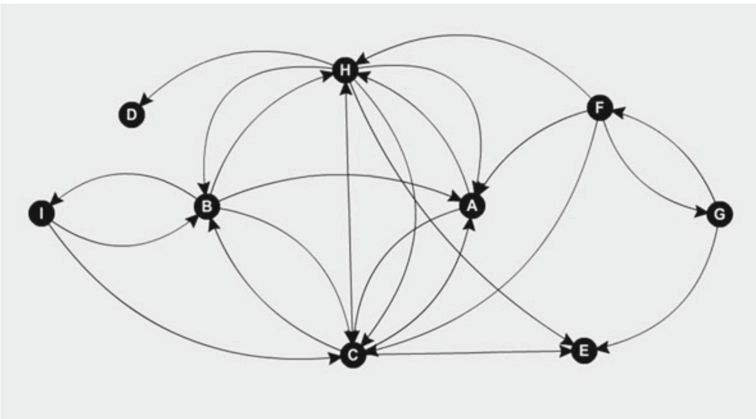

Fig. 1.4 Versatility-adaptability graph

1.5.3 Case Study

JUnit is a framework that allows code writing for repeatable tests. It is an instance of the xUnit architecture for unitary test frames. It is used to run unitary tests in Java applications (JUnit 5 2019). It was considered as a case study for pattern replacement since it is a commonly used system, which is stable and has a considerable level of maturity and complexity to develop replacement tests in a real-world environment. The system allows the assessment of methods' functionality of a class. Junit offers in its `org.junit.Assert` class nine methods which allow the testing of different conditions, which are `assertArrayEquals()`, `assertEquals()`, `assertTrue()`, `assertFalse()`, `assertNull()`, `assertNotNull()`, `assertSame()`, and `assertNotSame()` `y` `assertThat()`.

To verify the replacement capability considering the matrix results was designed a basic test which allows the recognition of patterns (or possible patterns) implemented inside JUnit to ensure that, after a substitution, the tests gave the same results. The test is presented as follows: given the `MyClass` Class of Fig. 1.5, it is desired to verify that the array containing the `getTheStringArray()` method of line 3 is identical to the array which contains the `MyClassTests` Class in line 8 of Fig. 1.6. For this, the `assertArrayEquals()` method was used, which compares whether the two arrays are equal. That is, if both contain the same number of elements and, also, if all the elements of the array are identical. If the condition is reached, the test ends successfully, if not, the test is aborted. Figure 1.7 shows the test result without making changes to JUnit.

After executing the test, it was necessary to identify the design patterns that JUnit had implemented in its code. The Design Pattern Detection v4.5 tool (Tsantalis et al. 2006) was used for this process. The tool detected 21 possible instances of the Strategy pattern. The aspect in Fig. 1.10 was used to verify that they were instances of the Strategy pattern. Such an aspect obtains a trace of the JUnit test execution. Such execution was used to identify an instance of the pattern, which is shown in Fig. 1.11. This instance is a strategy to build runners for classes. A client with a constructor

```
1 package junit;
2 public class MyClass {
3   public String[] getTheStringArray(){
4         String[] resultArray= {"one", "two", "three"};
5         return resultArray;
6   }
7 }
```

Fig. 1.5 `MyClass` class shows an array in its `getTheStringArray()` method

```
package junit;
import static org.junit.Assert.*;
import org.junit.Test;
public class MyClassTests {
  @Test
    public void testStringArray() {
    MyClass mc = new MyClass();
        String[] resultArray = mc.getTheStringArray();
        String[] expectedArray = {"one", "two", "three"};
        assertArrayEquals(expectedArray, resultArray);
    }
}
```

Fig. 1.6 MyClassTests class assesses if the two expected arrays are equal

taking a `RunnerBuilder` as a parameter will be passed to the `RunnerBuilder` instance used to create that same runner.

Thus, the Strategy pattern was selected for replacement; this corresponds to step 1 of the method to perform the tests presented in Sect. 1.5.2. Steps 2 and 3, which are the analysis of the pattern and identification of its medullar parts, were performed in a controlled environment with other tests apart from JUnit for identification purposes presented in Figs. 1.8 and 1.9.

Step 4 was omitted since no more aspects were made for substitution; therefore, it was not necessary to reuse some elements of the aspect for this case. For step 5, the Abstract Factory pattern was selected for being the first in the GoF catalog (Gamma et al. 1995), which presents versatility with Strategy.

Based on the structure of Fig. 1.12, adjustments were made to match the Abstract Factory pattern; thus, such a pattern may offer the same functionality as Strategy. It is worth mentioning that only four classes of the seven which are inherited from the `RunnerBuilder` class were taken since they were adjusted to the most basic structure of Abstract Factory.

Next, substitution testing was performed in Fig. 1.13. It is worth mentioning that, in the testing aspect, due to the nature of the structuring of the application, it was necessary to apply the cuts at a lower level in the hierarchy of strategies to guarantee the correct exposure of the context. The above corresponds to step 6 of the method of Sect. 1.5.2. Also, lines 21–23 of the aspect are an example of the application of step 7 of the method. Step 8 is performed by executing the aspect of the test shown in Fig. 1.13.

Before the change, there was a result that was compared to the result after the change. The result obtained after the change was the same. The same outputs were

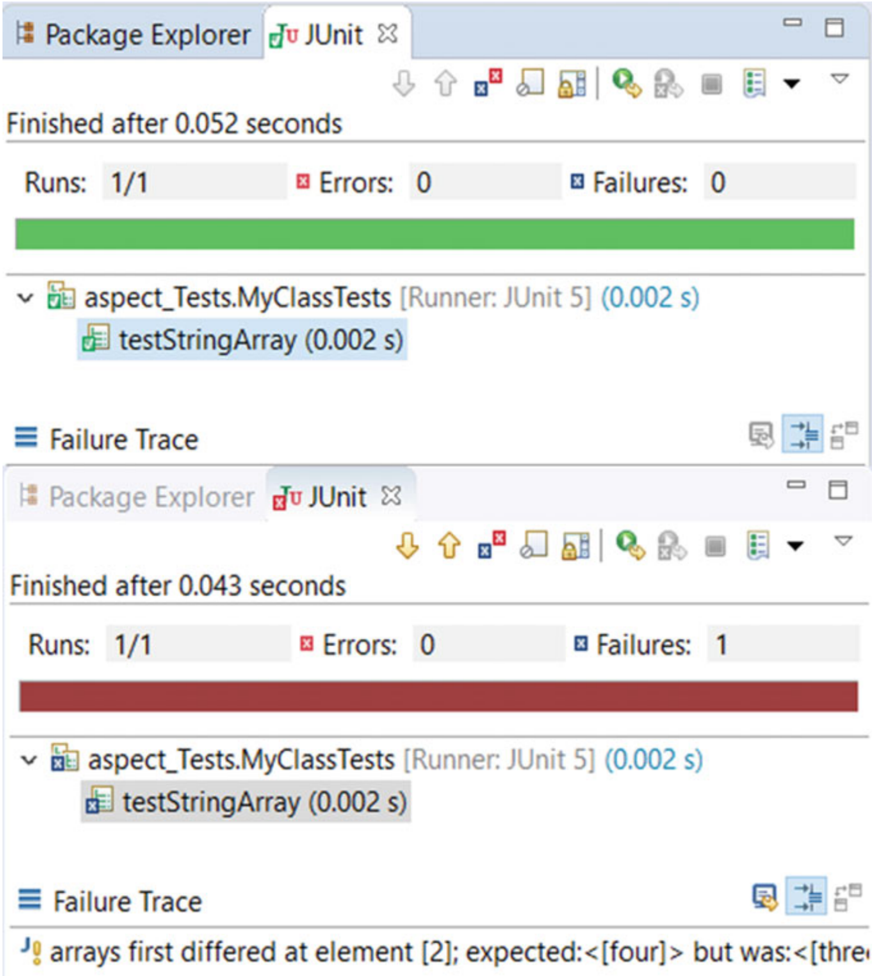

Fig. 1.7 Two possible comparisons between the expected arrays

obtained, and the tracking also yielded the same results. Consequently, that implies that at least this type of modification is consistent and safe; therefore, the exchange of patterns achieves the objectives which correspond to step 9 of the method. Finally, considering that the goals were achieved, step 10 is performed, taking the substitution as acceptable, concluding that the Strategy design pattern presents good adaptability using Abstract Factory as an example, facilitating its replacement.

```
package u24.functions;
import u13.abstract_factory.AbstractFactory;
import u13.abstract_factory.ConcreteFactory2;
public abstract aspect Abstract_AbstractFactory {
  private AbstractFactory f2;
  pointcut createMethodPA():
    execution (void u13.abstract_factory.ConcreteFactory2.createProductA());
  pointcut createMethodPB():
    execution (void u13.abstract_factory.ConcreteFactory2.createProductB());
  pointcut callSOP(AbstractFactory x):
    call(* java.io.PrintStream.print*(..))
    && args(x);
  pointcut mainCut():
    execution(void u13.abstract_factory.Aplication.main(..));
  before (AbstractFactory x): callSOP(x){
    f2=x;
  }
  void around (AbstractFactory x): callSOP(x) && within(u13.abstract_factory.Aplication){
    if(!(f2 instanceof ConcreteFactory2))
      proceed(x);
  }
}
```

Fig. 1.8 Abstract aspect for abstract factory pattern

1.6 Conclusions

The development and evolution of software with high-quality standards require the use of more and better strategies to ensure consistency in the implementation and improvement of requirements. This article presented the modification of the FOS algorithm to facilitate the transfer of a solution to a problem (design pattern) from other contexts (other design patterns) to obtain local improvements while preserving and improving software quality. The proper identification of functions for design patterns required the complete documentation available through their templates, the support of experts, and the consideration of including synonyms in functions to make the knowledge transference more flexible. The steps used to identify the functions allowed the creation of a potential substitution framework between patterns, from which it is possible to obtain their adaptability and versatility. The tests show that the implementation of the substitution between design patterns ensures structural similarity. Based on the results obtained and the case study presented, it is possible to appreciate (1) the flexibility of the FOS algorithm for design patterns, (2) how to use the substitution, and (3) how substitutions and their respective tests were performed through combined programming techniques to guarantee the stability of

```
package u24.functions;
import u18.strategy.ConcreteStrategyA;
import u18.strategy.ConcreteStrategyB;
import u18.strategy.Context;
import u18.strategy.Strategy;
public aspect AbstractFactory_Strategy extends Abstract_AbstractFactory{
  Context c;
  void around(): createMethodPA(){
    System.out.println("==␣Creating␣product␣from␣Strategy␣==");
    Strategy s = new ConcreteStrategyA();
    c = new Context(s);
    c.contextInterface();
    System.out.println("Product:␣"+s);
    System.out.println("====================");
  }
  void around(): createMethodPB(){
    System.out.println("==␣Creating␣product␣from␣Strategy␣==");
    Strategy s = new ConcreteStrategyB();
    c = new Context(s);
    c.contextInterface();
    System.out.println("Product:␣"+s);
    System.out.println("====================");
  }
}
```

Fig. 1.9 Abstract factory-strategy test

the system behavior, in this case, JUnit. In future work, it is essential to attend to the development of tools that support each one of the steps in the application of FOS for the substitution of design patterns. It is considered to implement a pattern substitution tool in a knowledge base based on the Prolog language to facilitate function search capabilities and develop a set of wizards that support the replacement of patterns based on versatility and adaptability graphs.

```
package aspect_Tests;
import java.util.logging.Level;
import java.util.logging.Logger;
import org.aspectj.lang.JoinPoint;
import org.aspectj.lang.Signature;
import org.aspectj.lang.reflect.SourceLocation;
import org.junit.runners.model.RunnerBuilder;
public aspect Tracing_Strategy {
  pointcut strategy19(Object c): //Instance 19 — Only this instance is a Strategy design pattern
    execution (* org.junit.runners.model.RunnerBuilder+.*(..))
    && args(c);
  pointcut strategy19Context(Object a):
    execution (* org.junit.internal.builders.AnnotatedBuilder+.*(..))
    && args(a);
  pointcut strategy19Construct(RunnerBuilder n):
    execution (org.junit.runners.model.RunnerBuilder+.new(..))
    && target(n);
  before(RunnerBuilder n): strategy19Construct(n){
    System.out.println("\n NEW ----" + n);
    printStaticJoinPointInfo(thisEnclosingJoinPointStaticPart);
  }
  before(Object c): strategy19(c){
    System.out.println("\n STRATEGY ----" + c);
    printStaticJoinPointInfo(thisEnclosingJoinPointStaticPart);
  }
  before(Object a): strategy19Context(a){
    System.out.println("\n CONTEXT ----" + a);
    printStaticJoinPointInfo(thisEnclosingJoinPointStaticPart);
  }
```

Fig. 1.10 Tracing aspect

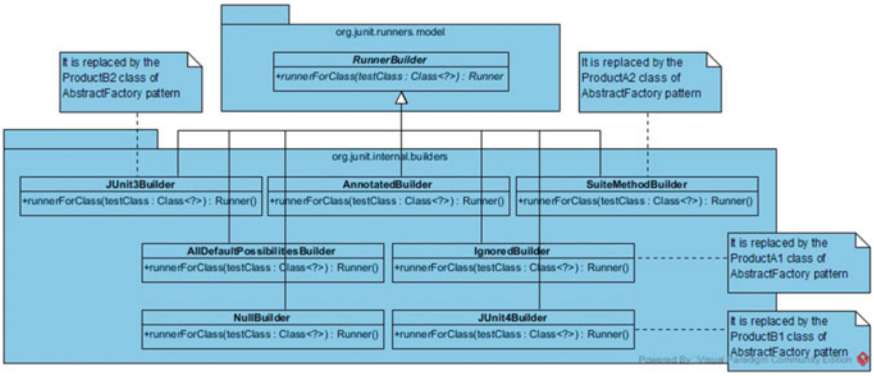

Fig. 1.11 Strategy design pattern in JUnit

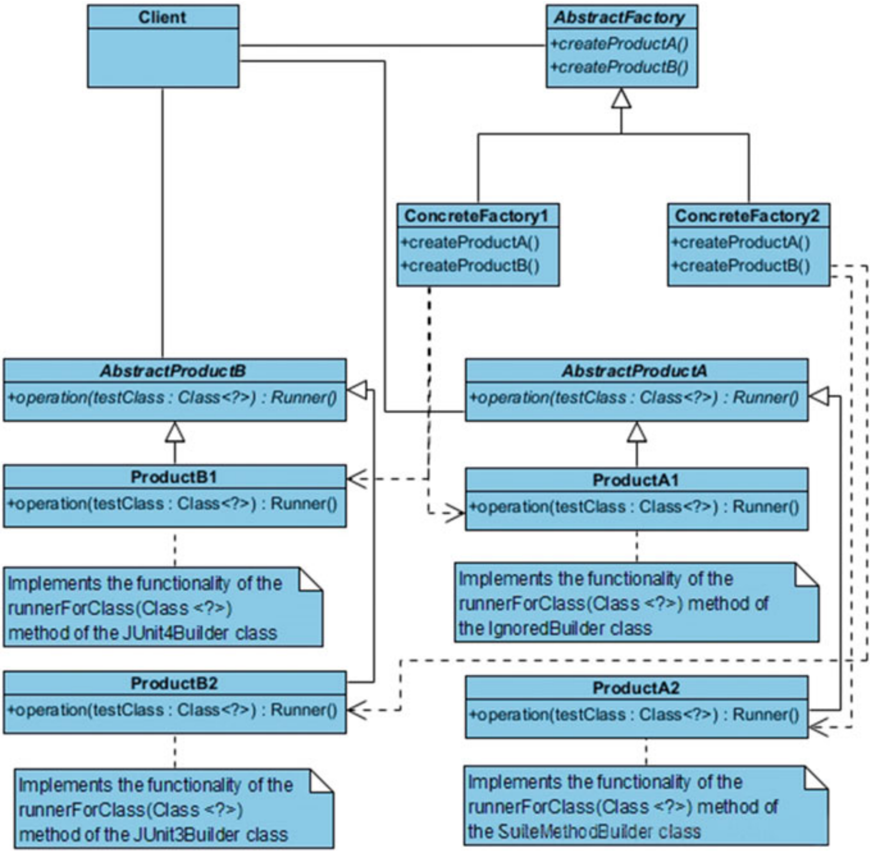

Fig. 1.12 Abstract factory design pattern structure to replace strategy

```
package aspect_Tests;
import java.io.IOException;
import java.util.Arrays;
import java.util.List;
import org.junit.internal.builders.*;
import org.junit.runner.Runner;
import org.junit.runners.BlockJUnit4ClassRunner;
import org.junit.runners.model.RunnerBuilder;
import abstractFactory.AbstractFactory;
import abstractFactory.AbstractProductA;
import abstractFactory.AbstractProductB;
import abstractFactory.ConcreteFactory1;
import abstractFactory.ConcreteFactory2;
public privileged aspect Strategy_Test19{
  AbstractFactory f1 = new ConcreteFactory1();
  AbstractFactory f2 = new ConcreteFactory2();
  private AbstractProductA ConcreteFactory1.getPa() {return pa;}
  private AbstractProductB ConcreteFactory1.getPb() {return pb;}
  private AbstractProductA ConcreteFactory2.getPa() {return pa;}
  private AbstractProductB ConcreteFactory2.getPb() {return pb;}
  pointcut strategy1(RunnerBuilder n, Class<?> a):
    execution (* org.junit.internal.builders.IgnoredBuilder+.runnerForClass(..))
    && target(n) && args(a);
  Runner around(RunnerBuilder n, Class<?> a) throws Throwable: strategy1(n, a){
    Runner r = null;
    System.out.println("---------------- Operation " + a);
    if (n instanceof IgnoredBuilder){
      System.out.println("---> Ignored Builder" + n);
      f1.createProductA();
      System.out.println("---> Product: " + ((ConcreteFactory1) f1).getPa());
      r= ((ConcreteFactory1) f1).getPa().operation(a);
    }
    else
      proceed(n, a);
    return r;
  }
  pointcut strategy2(RunnerBuilder n, Object a):
    execution (* org.junit.internal.builders.JUnit4Builder+.runnerForClass(..))
    && target(n) && args(a);
  Runner around(RunnerBuilder n, Object a) throws Throwable: strategy2(n, a){
    Runner r = null;
    System.out.println("---------------- Operation " + n);
    if (n instanceof JUnit4Builder){
```

Fig. 1.13 Substitution test

```
      System.out.println("---> JUnit4 Builder - " + n);
      f1.createProductB();
      r=((ConcreteFactory1) f1).getPb().operation((Class<?>)a);
    }
    else
      proceed(n, a);
    return r;
  }
  pointcut strategy3(RunnerBuilder n, Object a):
    execution (* org.junit.internal.builders.SuiteMethodBuilder+.runnerForClass
        (..))
   && target(n) && args(a);
  Runner around(RunnerBuilder n, Object a) throws Throwable: strategy3(n, a){
    Runner r = null;
    System.out.println("------------ Operation " + n);
    if (n instanceof SuiteMethodBuilder){
      System.out.println("---> SuiteMethod Builder - " + n);
      f2.createProductA();
      r=((ConcreteFactory2) f2).getPa().operation((Class<?>)a);
    }
    else
      proceed(n, a);
    return r;
  }
  pointcut strategy4(RunnerBuilder n, Object a):
    execution (* org.junit.internal.builders.JUnit3Builder+.runnerForClass(..))
   && target(n) && args(a);
  Runner around(RunnerBuilder n, Object a) throws Throwable: strategy4(n, a){
    Runner r = null;
    System.out.println("------------ Operation " + n);
    if (n instanceof JUnit3Builder){
      System.out.println("---> JUnit3 Builder - " + n);
      f2.createProductB();
      r=((ConcreteFactory2) f2).getPb().operation((Class<?>)a);
    }
    else
      proceed(n, a);
    return r;
  }
}
```

Fig. 1.13 (continued)

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Chapter 2
Product Personalization with TRIZ and CAI

Reyes Hernández Damna

Abstract This chapter describes a product personalization strategy applying the Theory of Inventive Problem Solving (TRIZ). The episode begins with a brief introduction about the opportunity to apply TRIZ tools within a methodology that benefits users to obtain a personalized product. This chapter also presents a summary of some topics related to the use of TRIZ and other disciplines to create new tools to assist conceptual design. The integration of TRIZ and Computer-Aided Innovation (CAI) tools is presented and explained as a customization process to be implemented in the conceptual design phase. The product personalization approach with the integration of TRIZ and CAI is oriented to formulate and reformulate the product design. Therefore, the importance of this chapter is to show how TRIZ assists in the process of designing custom products. CAI contributes to the development of new products. To conclude this chapter, is presented a case study on the implementation of the personalization strategy for a product in the conceptual design phase where are explain the concepts and methodologies.

Keywords Product design · TRIZ · CAI · Conceptual design

2.1 Introduction

TRIZ has the advantage of being a tool oriented to apply in different disciplines and methodologies; this chapter highlights its application in the Computer-Aided Innovation (CAI) area. CAI is useful to solve inventive problems in the personalization of products. The solution of inventive problems allows the design of products to have different aspects in which you can use tools that favor the development of innovation.

Since companies are in a dynamic market, the search for new strategies is necessary to offer their products or services. In this case, innovation makes sense because it's the consequence of the connection between a creator with ideas that can change a product (Carayannis 2020). From this perspective, innovation is a factor that, together

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with technological tools, benefits businesses and emerging markets. Therefore, when organizations do not invest in reinventing their industry (new and attractive products and services), they have vanished in a competitive environment. For Latin America, the scenario indicates that there is little openness to innovation since it is characterized as one of the regions where organizations operate without considering technological evolution. Likewise, this context is at a disadvantage when it comes to the generation of new products, patents, and investment in research and development (Geršak 2013). However, product customization allows the user to obtain a new and attractive product with features according to their requirements and needs. The above is because the client has chosen to value differentiation and selectivity. That is why it is necessary to identify what the client's voice says to know what their requirements are and focus the organization's resources on the conceptual stage of the design process. Based on the above, a brief description of the methodology and tools used in the product customization strategy with TRIZ and CAI is present, where the use of TRIZ tools and computer-aided innovation (CAI) in product development is explained in detail through customization.

2.2 Product Personalization

Product personalization is the subject of arduous research as it is subject to changes arising from customer behavior and consumption habits. Therefore, the challenge is to follow up on each aspect that the client considers essential. In turn, the design area will have to timely consider the complexity of massive customization if there are many variables (Porcar 2003). Likewise, the participation of the client in the design and creation process allows the individual and emotional selection of the functional, physical, and, sometimes, technical characteristics of a product made exclusively to preferences that the client is looking for.

After obtaining the requirements and characteristics of a product, it is necessary to solve some problems that may present restrictions in the technical descriptions of the product. The next part of the process requires documentation that includes the lists of materials, production cycles, and inventory codes, among others. However, this stage varies according to the type of product and company that executes the process.

Within this framework, it is essential to emphasize that personalization becomes mass customization when it can offer products or services designed from standardized processes and systems (they are flexible, low cost, efficient, and effective) (Geršak 2013). To better understand mass customization, Gilmore (1997) proposes four approaches.

- Collaborative personalization establishes already personalized options so that the client can choose between one of these.
- Adaptive personalization provides a standard product with the option to adapt it according to market requirements.

- Cosmetic personalization provides a standard product for different consumers (the packaging is customized); however, it does not offer a customizable product.
- Transparent customization is what gives the customer a unique product or service, but without informing them that the products had a manipulated development to identify with them.

These four approaches support the development of design strategies with the ability to create customization to meet the individual needs of customers. Hence, it is in the conceptual design phase of the product where it is possible to integrate strategies to apply innovative strategies and interpret the voice of the client to produce better design options and obtain, as a result, new useful functions (Uribe Becerra 2011).

2.3 Conceptual Design

Studies on conceptual design show that at this stage, there are different solution options for design problems. Some of the authors define conceptual design as that stage of the design process where a mental exercise for the analysis of the most critical problems of creating a product is important, and determining what the structures, requirements, principles, and demands of the clients to develop a solution are (González López 2016; López Soto 2013; Ariza 2009; Neill 1998).

In this sense, conceptual design involves a series of ordered and finite steps to analyze the needs of customers and generate conceptual products that approach the development of the final product. In general terms, the product construction process begins at the conceptual design stage, and technical, functional, and cost aspects must consider. Similarly, product development is essential for the process of survival and business development (Castro 2018).

2.4 Computer-Aided Innovation

Software development has allowed the creation of tools that promote innovation. Computer-Aided Innovation aims to support innovation and the development of new products (Leon 2009). The relationship that exists between TRIZ and CAI is through collaboration to solve inventive problems through contradictions, resources, separation principles, and ideal systems, to name a few.

The importance of applying CAI in this strategy is because of its robust development in computer tools that help search for knowledge faster. It is desirable that, in this process, the information collected through the sources of knowledge (patents, scientific publications, and research) recognize trends and how to convert the data collected into a report to make decisions and avoid risks. In turn, the results should build a useful element for the development of knowledge and the updating of the different technologies and changes related to products (regulations, leadership systems, research evolution, and new patents).

As a result, CAI provides advantages in innovation processes to make them more efficient, in addition to using tools aimed at developing innovation. The benefits of combining TRIZ-CAI are the stimulation of creativity and the use of techniques to generate inventive ideas (Lopez Flores 2015).

Therefore, TRIZ is a useful tool for the development of innovative products and offers solutions to inventive problems. There are some limitations that must be counteracted through a flexible strategy, and this strategy is useful to designers. Following this logic, CAI creates custom products by identifying customer requirements. The proposal is through a prototype of open CAI software in the process engineering of the chemical industry (Dereli 2013). Therefore, the advantage of creating a customization tool through CAI is that there are different CAI tools based on TRIZ that are potentially useful to solve the problem of customized products (Becattini 2012; Mohamed 2005; Belski 2009).

2.5 Product Personalization in the Conceptual Design Phase

In the previous section, there is a brief concepts and tools explanation that established the basis for the development of this work focused on the development of customized products. Large companies in Latin America typically have a low investment to produce customized products. However, people seek to identify with the products they use. A custom product configuration is a tool that allows interaction between the customer requirements and a product.

A personalization product is possible through a strategy that combines the product design process, information technologies, production, and manufacturing techniques. The result is a configuration system customized based on knowledge so that a product adapts to the requirements demanded by the customer. Therefore, personalization must have the purpose of finding new facets of the product to extend its potential market.

2.5.1 Personalization Strategy

The customization process needs the customer's participation in the early design stages. Some studies defend the idea of creating families of products to customer requirements. Based on this idea, the primary purpose is to maintain the use of computer tools to provide customizable products (Liu 2014).

Other authors, however, establish a specific customization procedure through three stages Kaneko (2017) a process of designing, manufacturing, and supplying different products and services for each user individually.

2.5.2 Phases' Description

There are different tools to customize a product; however, the crucial step is to know what is design strategy that meets the needs of customers in the early stages of design. Hence, the strategy must consider the needs of customers, deploy a user-oriented design process, consider a flexible manufacturing process, and the variety of configurations through computer tools. Figure 2.1 presents this personalization strategy for the conceptual design of the product.

1. Technological surveillance: the historical background and trends of the product identified through technological surveillance, in addition to determining the advantages and disadvantages that the results may present.
2. Listen to the client's voice: when selecting the product to be customized, the following is to define the customer segment. Simultaneously, in the customer requirements to formulate the concept of an ideal system, it is advisable to identify the TRIZ resources and apply QFD survey (Quality Function Deployment process).
3. Transform the client's voice into demands: The client's voice leads to some crucial information which is transformed into a list of requirements. These requirements have a hierarchy: primary and secondary demands. Primary demands are achieved through the manipulation of secondary demands.
4. Transform the client's voice into specifications: Once the customer's demands are hierarchized, the result is the functional demands of the customized product (function diagram).
5. Conceptual design of the customized product: In the last stage, the team or user formulates the conflicts in the system using the TRIZ contradiction philosophy (physical or technical) according to the product functional diagram. Later, it is necessary to solve the contradictions by selecting the right tool: separation principles in the case of a physical contradiction or the contradiction matrix if the conflict is a technical contradiction. The user transforms these suggestions into potential solutions, which are later compared to the characteristics of feasible solutions. Finally, at least a conceptual design of the chosen solution is represented in this stage.

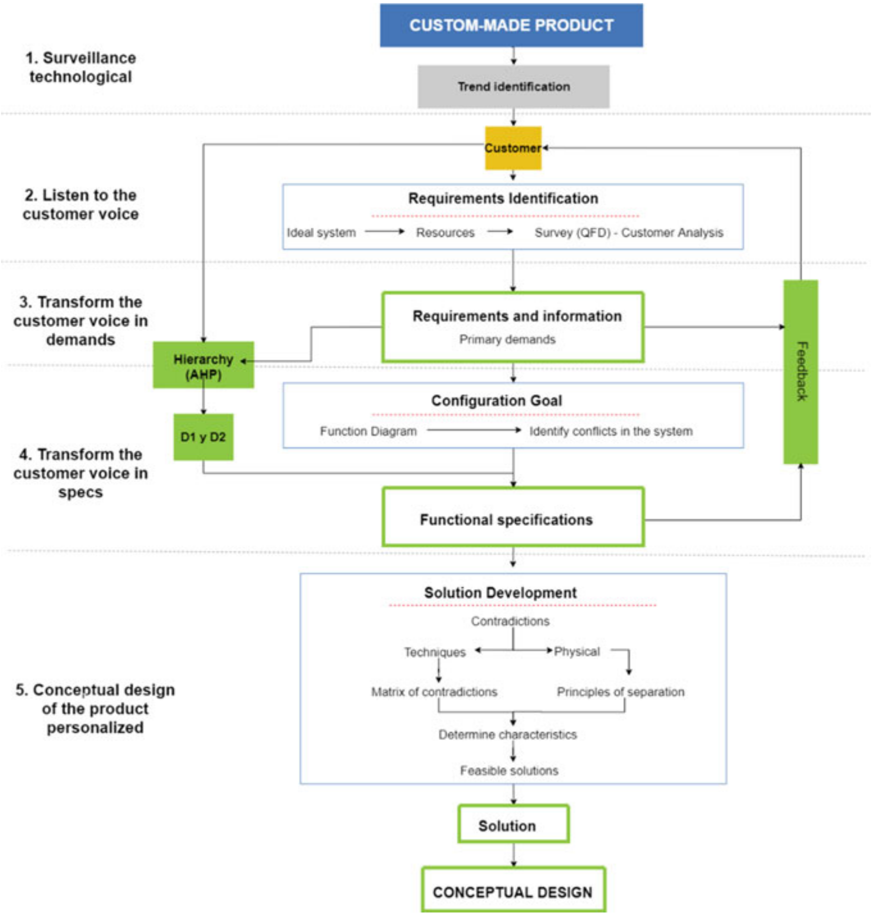

Fig. 2.1 *Source* Own elaboration based on (Kaneko 2017) with a methodology that combines TRIZ and CAI for the personalization process

2.6 Case Study

2.6.1 Following the Personalization Phases

This section offers an example of the development of a custom toy in the conceptual design phase.

– **Description of the product**

It is an assistant for early language stimulation. It works through an interactive system that supports children's learning and complements the development of communication. It includes speech traits, psychomotor skills, and sensory senses (all of these are

Fig. 2.2 Interactive toy, case study

necessary for the communication process to take place). The interactive toy (Fig. 2.2) is the one that constitutes an integral system for the improvement of speech quality.

– **Technological surveillance through software**

The purpose of technological surveillance is to offer a brief perspective on the main technological developments that coincide with the interactive toy for language stimulation. One of the main reasons for carrying out technological surveillance is to identify and assess those technological advances that could be relevant for the development of a project or strategy for the creation of new products. It is necessary to point out that there are differences between technological surveillance and benchmarking. The first identifies collateral technological trends (technological developments that do not necessarily belong to a technical domain), while benchmarking compares processes, products, services, or methodologies between those companies or other organizations (PNT 2018; Bogan 1994). The solutions proposed by the CREAX company were useful to execute this task. Finally, this surveillance or technology landscaping has other advantages:

– Identify unique characteristics in a product.
– Highlight specific attributes of a product or technology or isolate the main ones.
– Identify areas of opportunity on the modifications that a product or technology must undergo.
– Identify the main competitors to assimilate their technology.
– Identify the sources of knowledge generation to make strategic alliances.
– Identify other potential markets for a product or technology.

The process followed for the elaboration of this analysis was mainly based on the combination of various search methodologies in patent bases such as in the United States Patent (USPT), Espacenet, (Michel 2006), and by various solutions of reported software, including the most relevant Goldfire Innovator of the company IHS (Goldfire 2018). Therefore, the essential stages of technological surveillance are as follows.

– **Identification of codes in patent bases**

The international and regional codes of the European Union (EU) were selected, as well as the US patent bases for a prior ambiguity reduction process (without this process, the number of patents to consider would be high). The codes were selected based on the objective of the case, the technology used, and the trends of evolution detected by the team. Concluding this phase, the Cooperative Patent Classification (the joint work between the US Patent Office and the European Patent Office) is used to migrate toward a patent classification that is common in both regimes. Concerning the application of the patent search in Mexico, the team considers a search on the platform of the Mexican Institute of Intellectual Property.

– **Selection of the terminology relevant to generate semantic searches**

The work team used the following keywords to filter the selected attendee codes: interactive toy, language development, personalization, a toy for language, educational toy, interactive toy for communication, interactive communication toy, and interactive toy pronunciation, to mention some of the terms used. The software used made a series of recommendations to filter the result.

A tag cloud organizes the information; it uses a practical and straightforward logic, that is, the larger the font size, the more critical the search object (Fig. 2.3).

The result of these terms is to generate the first classification for the selected patents. Table 2.1 lists the terms with the highest number of patents, which is equivalent to the terms with the most registered patents.

The selected patents are mostly related to the following terms: toy with 2387 patents, response with 1213, a game with 1005, in addition to a speaker with 202, and speech with 242. Therefore, these words correspond to the objectives of analysis

Fig. 2.3 Terminology suggested by patent software

Table 2.1 Suggested terminology to apply filters in selected patents

Term	Number of patents	Term	Number of patents
Advertisement	219	Mode	288
Animal	367	Motion	523
Article	235	Network	767
Aspect	228	Parameters	288
Audio	290	Person	279
Camera	287	Platform	208
Card	230	Player	370
Character	421	Processor	593
Child	416	Recognition	275
Children	386	Representation	291
Database	278	Response	1213
Disclosure	310	Sequence	298
Doll	283	Server	422
Entertainment	362	Software	375
Event	351	Speaker	202
Experience	317	Speech	242
Feedback	265	Tag	207
Game	1005	Target	216
Identification	302	Techniques	282
Internet	339	Toy	2387
Item	452	Variety	216
Media	420	Video	528
Message	358	Voice	301

and, consequently, they can match the intended functionality with the case under development. The selection of the appropriate terminology can be used as a hyperlink to consult specific patents that contain this term. This functionality is the result of the analysis of patent extraction.

– **Trend charts' elaboration**

Once the filters were applied to select patents, the results underline a domain that reveals the highest activity in the generation of patents G05B15 is related to computer-controlled systems (code that is essential in this project) (Fig. 2.4). Also, in this category, there are communication systems between different components. Code G10L25 is included because it contains patents related to the generation of information transmitted through language (Fig. 2.5).

The in-depth search reveals functionalities that are similar to the objects of analysis. After doing a thorough investigation into the digital codes chosen to carry out

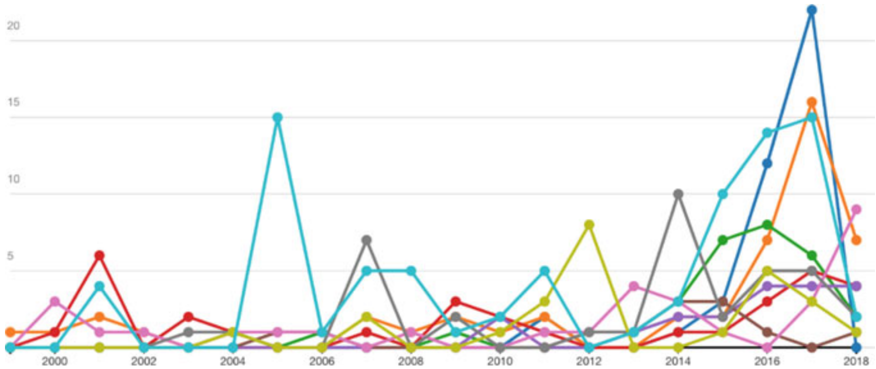

Fig. 2.4 Patents' tendency

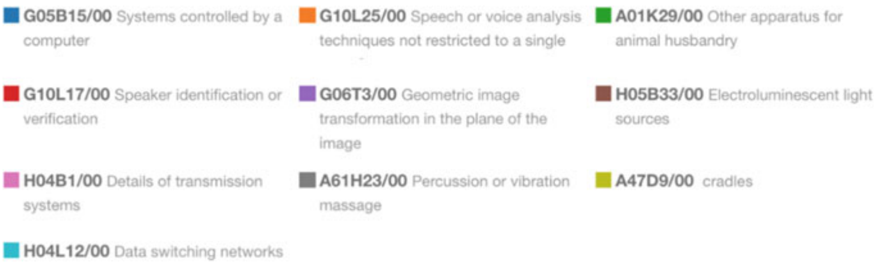

Fig. 2.5 Patents' tendency selected by code

the technological surveillance, verify the following classifications (according to the importance of the domain), Fig. 2.6.

By grouping all codes and classifying them according to the year of creation, the results show a different trend outlined in Fig. 2.7.

As a result, technology has a curve that explains its development. In general, the case study system is just beginning its development. The curve's slope in the graph indicates these systems have proper assimilation by the market, despite the decreases in the pace of patent generation. At the same time, despite these fluctuations, it is possible to point out that the domain maintained a natural S curve at its development stage. The patent classification by country in Table 2.2 reveals an interesting dynamic. The USA is the country with more registered patents.

Table 2.2 also indicates that Mexico (the only Latin American country on the list) has two patents applied for within the domain. It is possible to conclude that there are few developments in Mexico related to the design of language assistance systems that use a toy. And that, besides, there is no clear competitor in the Latin American market.

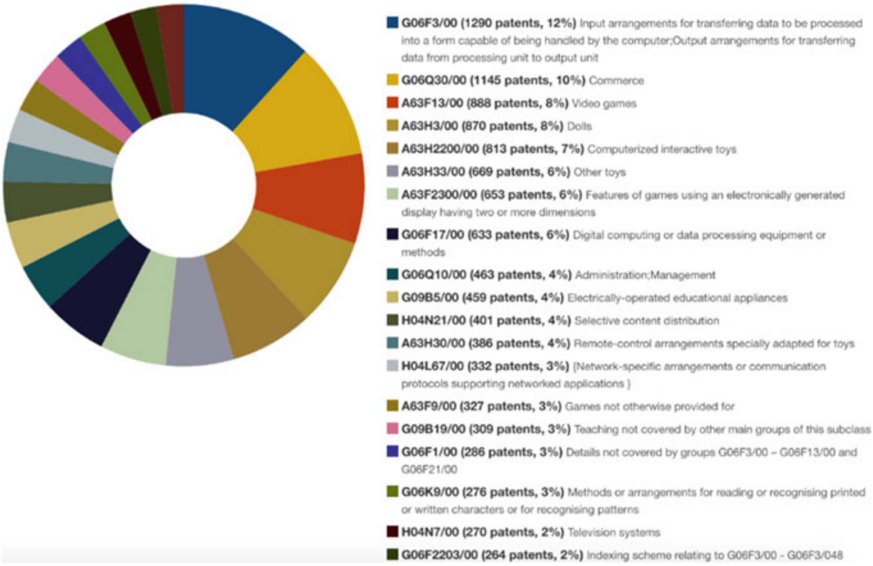

Fig. 2.6 The proportion in the generation of patents is classified by codes

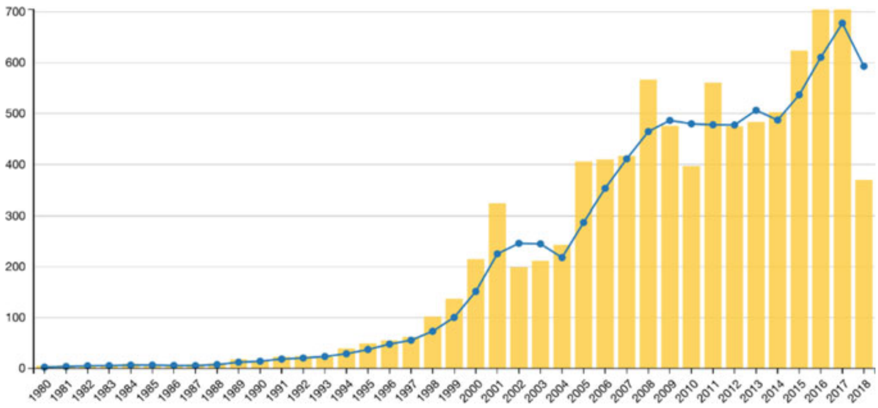

Fig. 2.7 Patent' production is classified by years

– **Classification graphs using tag clouds**

The tag cloud corresponding to the inventors is generated from the number of patents generated by them, as shown in Fig. 2.8.

According to the results obtained, Table 2.3 contains the tags' cloud.

– **Patents' valuation according to the identified domains**

Table 2.4 briefly describes the primary inventions related to interactive toys.

Table 2.2 Patents' list by country

Country	Patents
United States	5586
China	489
United Kingdom	346
Israel	333
Canada	272
Japan	248
Taiwan, Province of China	155
Netherlands	108
Hong Kong	93
France	88
Mexico	2

Fig. 2.8 They are leading technology developers classified by their frequency of patents' generation

Table 2.3 Tag's table

Company	Number of patents registered
Apple Inc.	406
Mattel Inc.	251
Disney Entpr	158
Microsoft	117
Ganz	81

Table 2.4 Relevant patents' analysis

Document no	Applicant and year	Description and relationship with the project
EP3400994A1	(Patent Núm. EP3400994 (A1) 2018)	Interactive (robotic) toy. The head is detachable. It has at least one sensor
US2018318723A1	(Patent Núm. US2018318723 (A1) 2018)	Wireless communication. Information stored internally. The system applied to a plush material. Personality traits. A simulated intelligent system
US2018214786A1	(Patent Núm. US2018214786 (A1) 2018)	Toy made up of an assemble able kit. The user can choose the settings
US2018214787A1	(Patent Núm. US2018214787 (A1) 2018)	The toy plays sound or speech effects. The toy can display images on a screen and at the same time emitting sound signals or infrared
US2018211559A1	(Patent Núm. US2018211559 (A1) 2018)	This product is a cognitive system that includes an interactive device (toy). This system communicates with the user. Different levels of communication. Adaptable to the level of communication and language
US2018122266A1	(Patent Núm. US2018122266 (A1) 2018)	This product has methods and systems for learning languages interactively that include sounds, syllables, words, sentences, stories, assessments, and tasks. It can apply to a toy running a language learning app
US2017157522A1	(Patent Núm. US2017157522 (A1) 2017)	This document is about toys that can expand. Depending on how many elements are connected, you may have a better interactive response. Communicate with other characters belonging to the control unit. Interactions are auditory and visual
US2017065879A1	(Patent Núm. US2017065879 (A1) 2017)	It is an interactive toy that works under virtual and physical elements. It can store information that describes a character's attributes and abilities. The toy evolves based on the player's performance

(continued)

Table 2.4 (continued)

Document no	Applicant and year	Description and relationship with the project
US9457281B1	(Patent Núm. US9457281 (B1) 2016)	This item has interactive communication methods between an object and a smart device (with bidirectional communication). It is capable of transmitting words and songs
US2016206962A1	(Patent Núm. US2016206962 (A1) 2016)	Interactive communication methods between an object and a smart device. It is capable of transmitting words and/or songs. Communication can be bidirectional
US2016184724A1	(Patent Núm. US2016184724 (A1) 2016)	The Apps allow user to incorporate a toy or real objects into the application. A database is the one that gives the information to the toy
US2016175723A1	(Patent Núm. US2016175723 (A1) 2016)	The toy is considered a companion for the child. It is related to the areas of learning, entertainment, and security. It stands out because functionality and physical elements are programmable by installing apps from an app store
EP3100609A1	(Patent Núm. EP3100609 (A1) 2016)	An interactive system into toys considered pets. It has a communication module, phonation (configured to play voices in real time). Remote interaction between the owner and the toy is possible

After selecting the most related patents, the results were as follows: The most significant number of patents belong to the United States and China. Toy companies are interested in patenting the new functionalities of the devices. Some authors have renewed their inventions and documented them. For its part, Mexico does not show any transcendent patent in this area.

The main observation concerning the toy: In 2016, several apps were integrated into the toys to focus them on areas of learning and communication. In 2017, the toys incorporated virtual elements for more significant interaction and communication than other items. In 2018, the toys included more devices to make the systems more robust. Also, it seeks to configure the gadget to customize it and improve the gaming experience.

– **Elaboration of a cross-sectional analysis between domains in which a function must transfer or be assimilated**

Figure 2.9 shows a great diversity of domains that matches the functions of the case. This result implies that there may be developments in other technical areas (they could assimilate into the design or redesign of a detection system at a minimum cost).

After selecting the most related patents, the results were as follows: The major number of patents belonged to the United States and China. No clear competitors are present in the Mexican market.

Opportunities:

- It is important to increase the robustness of the object, but it also remains as light as possible.
- It is necessary to customize the object with the goal to increase the user's adoption.

Disadvantages:

- Mexico does not show any transcendent patents in this area.
- It can represent a competitive challenge against highly positioned companies.

Therefore, the next phase focuses on listening to the client's voice to identify the requirements.

2.6.2 Listen to the Client's Voice

The purpose of this activity is to identify children's needs when they are playing or interacting with the toy to understand how the object is used, what routines the children implement, and how long the object attracts the attention of the user, among other relevant questions (Pinos Cisneros and Escobar Vega 2021). The concept of an Ideal system and resource identification are the tools to define the characteristics to customize the product. Then, it is possible to conduct some surveys so that the client determines the importance of the requirements of the customized product. It

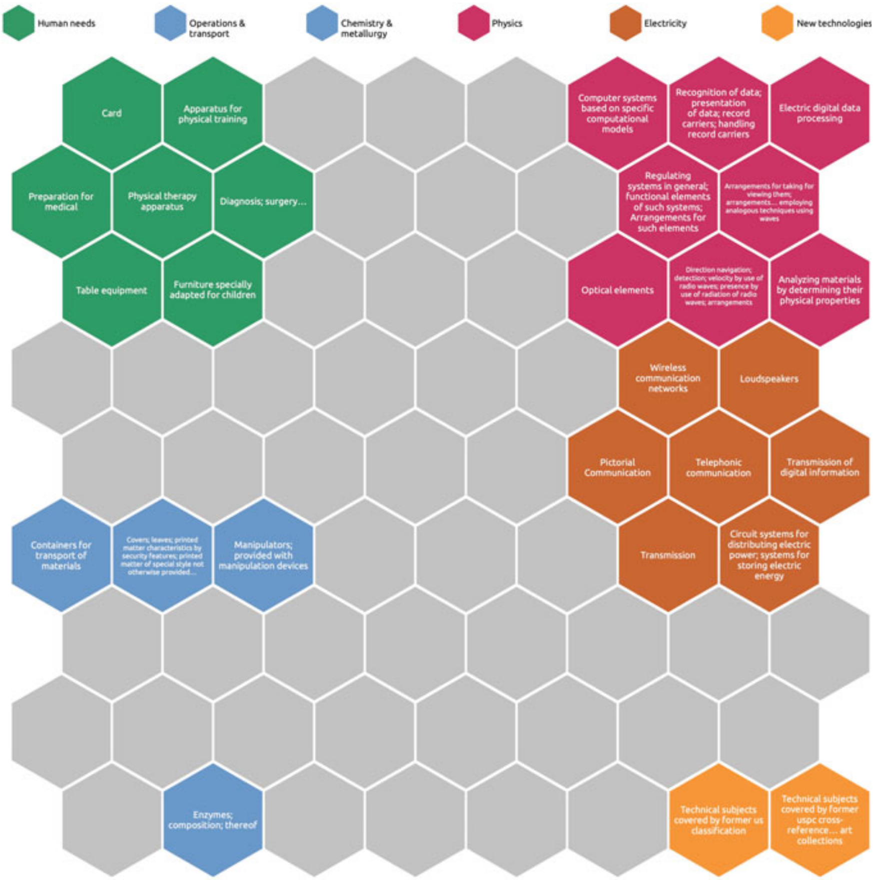

Fig. 2.9 Domains related to the project

is important to emphasize that the number of acceptable surveys should be applied from 20 to 30 people, as these are sufficient to understand the voice of the client (Terninko 1997).

Client

The study case is a product aimed at a market segment where the consumer is over two years old, and their parents are economically active with an interest in investing in the education of their children. Specifically, this toy will be tested in the Mexican market.

Ideal system

- Eliminate deficiencies: The product itself must be able to offer other functions, be attractive, and can be equipped with accessories according to the user's requirements without any loss of time or conflicts among components.

- Preserve the advantages: The object allows a stimulant game interaction.
- It does not increase complexity: Children and parents execute the customization process without any problem.
- It does not generate new disadvantages: Its production costs do not increase; it is friendly to the environment and easy to use.

Resources

- Environmental: the use of the product according to the user's activity, for example, the toy can use in different contexts (home, school, party, and field, among others).
- Spatial: the object is used horizontally, vertically, and has different sizes and specific shapes of the child's age size.
- Substances: among the materials used to make the toy, including plastics and fabrics.
- Energy resources and force fields: Sunlight, sound, and user energy that interacts with the toy.
- Information resources: Generally, the system is customized and represents the identity of the user or the context belonging to the client.
- Functional resources: The toy is used as a companion to the child's games; as a promoter of experiences for the stimulation of the child's senses, it generates confidence in the user to interact with the environment.

Survey

It's fundamental to identify the customer needs and to set up an expert panel. In this project, 20 experts were selected (following the AHP methodology) to configure the product (Fig. 2.10).

The primary demands detected are

- Functionality.
- Comfort.
- Esthetic.
- Safety and hygiene.
- Marketing and presentation.

Next, each of the primary demands is decomposed into secondary demands, which are all controllable.

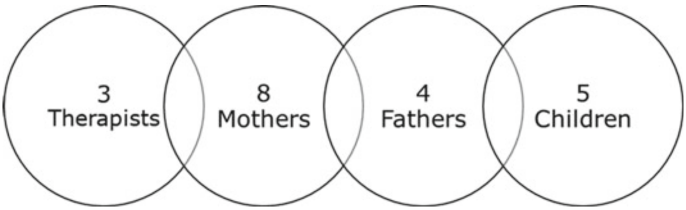

Fig. 2.10 The expert panel

Functionality

- Adaptable to the child's language problems.
- Personalized assistance.
- Speech therapy.

Comfort

- Softness.
- Portable.
- Funny.

Esthetic

- Shapes (round, humanoid, polygonal, no specific form).
- The texture of the material (plastic, fabric).
- Size (length, volume).
- Colors (different).

Safety and hygiene

1. Without edges.
2. Not toxic.
3. Easy to clean.
4. Resistant.

Marketing and presentation

- Accessible (easy to find in the marketplace).
- Attractive accessories to the market (clothes, friends, items, and food, among others).
- Accessible price (affordable).

2.6.3 Transform the Client's Voice Into Demands

The importance of children's participation, based on a field study, collects the primary demands (D1) of the client. The most relevant demands or requirements are

1. Aesthetics.
2. Functionality.
3. Marketing and presentation.
4. Safety and hygiene.
5. Comfort.

However, not all demands have the same importance. The Analytical Hierarchy Process (AHP) (Pakizehkar 2016) is useful to rank a set of attributes or variables. The results of this process are depicted in the next tables. Table 2.5 lists the code for each primary demand of essential requirement.

Table 2.5 List of demands for the personalization process

Letter	Variable
F	Functionality
SH	Safety and hygiene
C	Comfort
MP	Marketing and presentation
E	Esthetic

Table 2.6 shows how the expert panel perceives the importance of each pair of attributes, and Table 2.7 shows the results of the calculated weight of each primary demand.

In the Pareto diagram, it can be determined that the impact of each of the demands are those defined in Fig. 2.11 (Table 2.8).

Then, it is necessary to decompose each primary demand into secondary demands or secondary attributes, which are typically under the designer's control. Later, a

Table 2.6 Primary demands in comparison to the criterion of importance

Primary demands					
	E	F	MP	SH	C
E	1.00	3.00	5.00	7.00	9.00
F	0.33	1.00	3.00	5.00	7.00
MP	0.20	0.33	1.00	3.00	3.00
SH	0.14	0.20	0.33	1.00	3.00
C	0.11	0.14	0.33	0.33	1.00
Total	1.79	4.68	9.67	16.33	23.00

Table 2.7 Weighted primary demands

	E	F	MP	SH	C	Total	Average	Weight
E	0.56	0.64	0.52	0.43	0.39	2.54	0.51	50.00
F	0.19	0.21	0.31	0.31	0.30	1.32	0.26	26.00
MP	0.11	0.07	0.10	0.18	0.13	0.60	0.12	13.00
SH	0.08	0.04	0.03	0.06	0.13	0.35	0.07	7.00
C	0.06	0.03	0.03	0.02	0.04	0.19	0.04	4.00
Total	1.00	1.00	1.00	1.00	1.00	5.00	1.00	100.00

Table 2.8 The calculated consistency index

Lambda max	5.322871839
IC	0.08071796
RCI	7%

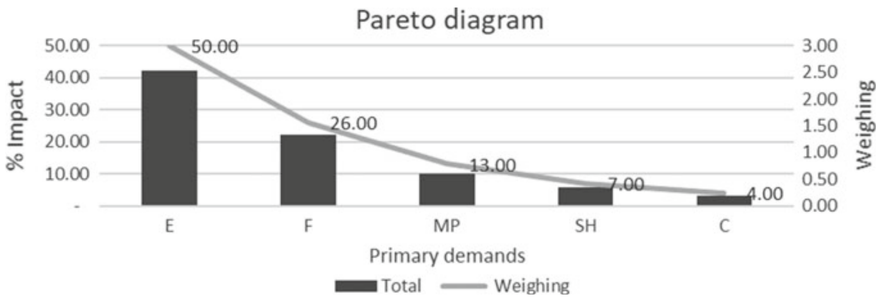

Fig. 2.11 Pareto diagram of the primary demands

second round of the AHP is necessary to calculate the weight of each secondary demand. The consistency index calculated in the AHP is acceptable (according to the Saaty scale) since the consistency index is less than 0.1 (Saaty 2008). The order of importance of the client's requirements was determined based on the results of the matrix of primary demands: esthetics, functionality, marketing, presentation, safety and hygiene, and comfort. Table 2.9 shows the AHP summary of primary and secondary demands.

Table 2.9 Summary of secondary demands

Primary demand	%	Secondary demand	Average	Importance
Esthetic	51	Shape	0.56	0.28
		Colors	0.26	0.13
		Material texture	0.12	0.06
		Size	0.06	0.03
Functionality	26	Adaptable to the child's language problems	0.63	0.16
		Speech therapy	0.26	0.07
		Personalized assistance	0.11	0.03
Marketing and presentation	12	Accessories	0.63	0.08
		Accessible price	0.26	0.03
		Accessible (easy to find in stores)	0.11	0.01
Safety and hygiene	7	Not toxic	0.56	0.04
		Easy to clean	0.26	0.02
		Resistant	0.12	0.01
		Without edges	0.06	0.004
Comfort	4	Funny	0.63	0.03
		Portable	0.26	0.01
		Smoothness	0.11	0.0042
Total	100			1.00

2.6.4 Transform Customer Voice into Specifications

A functional diagram is necessary to obtain the functional specifications of the customized product (Bytheway 2007). The purpose of this diagram is to visualize the personalization objective through a scheme where the system elements interact. The functional analysis diagram is also useful to identify the conflicts that arise in the system. It is important to note that the primary function of the system is to contain components that are part of the toy's system. The components in the system are connector, power source, cables, tube, movement, box, hardware, fabric, accessories, head, and motor. The components present a relationship, as demonstrated by the functional diagram in Fig. 2.12.

Figure 2.12 explains that when making modifications to the toy's functions, the hardware is modified and alters the structure of the box. It is essential to specify that the next section only shows how to deal with the customization process of the aesthetic demand.

Conflict identification

After detecting the harmful effects in the functional diagram, the next step is to select the conflicting elements: box-hardware, box-tube, head-hardware, fabric-connector, and motor-extremities.

These components are taking into account the secondary requests (Table 2.11) that are related to product customization. The characteristics that most interest customers are shape, color, and texture of the material. How to modify the toy so that it has different forms? How many colors can be changed? What variety of materials can the customer choose?

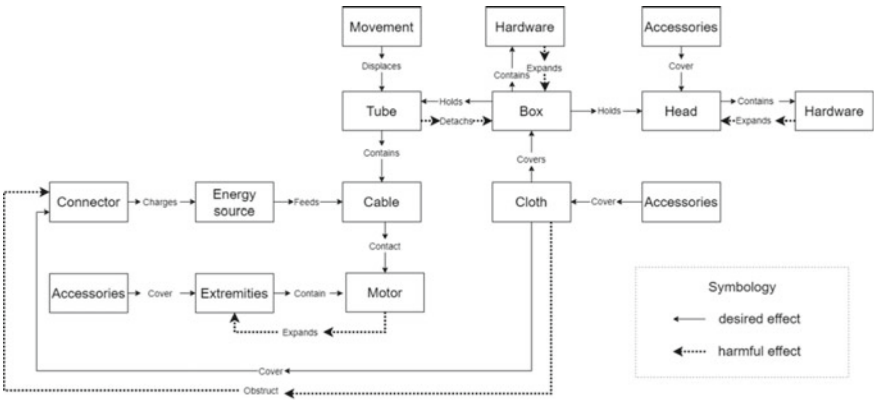

Fig. 2.12 Function diagram

Table 2.11 Secondary demands for personalization product

We will select	Importance
Shape	0.28
Colors	0.13
Material texture	0.06
Size	0.03
Adaptable to the child's language problems	0.16
Personalized assistance	0.03
Accessories	0.08
Accessible price	0.03
Accessible	0.01
Not toxic	0.04
Easy to clean	0.02
Without edges	0.0040
Funny	0.0253
Portable	0.0104
Smoothness	0.0042
Total sum	0.92

2.6.5 Conceptual Design of the Customized Product

During this stage, there are determined and resolved contradictions (physical or technical) based on the functional requirements and the client specifications. With the generated alternatives, it is possible to propose different combinations that propose new and feasible solutions for the system. The result is a proposed solution.

Contradictions

According to the functional diagram, the size head and the box are restrictive elements and cannot be modified, because the hardware is the same for all toys. Hence, the conflict leads to a physical contradiction:

- The object should be rigid and flexible at the same time.
- The toy must not only be small, but also it must be large.

Determine features

Concerning the functional diagram, the toy's box is the element considered as a body trunk; this is a rigid element that alone must fulfill functions to contain and hold.

The separation principle

The separation between parts and whole is a useful principle when a requirement exists in a crucial subsystem level but does not exist or has the opposite value at the sub-subsystem, and/or at a different systemic level. The hardware allows the box to have different sizes. However, it is limited because not all toys have the same functions. For example, by modifying limbs and accessories, they can become a system that eliminates the contradictions with the principle of separation of the whole and its parts.

Feasible solutions

The toy has some components that do not produce contradictions (it is necessary to remember that the toy has a humanoid structure):

- Material: plastic, and cloth.
- Size: small, medium, and large.
- Arms.
- Legs.

According to the functional diagram, the size head and the box cannot be modified, and this is because the hardware is the same for all toys. The toy arms and legs have the next alternatives:

- Material: plastic and cloth.
- Size: small, medium, and large.

With this information, the elements that can be customized are

- Material: Cloth.
- Head accessory: helmet, without a helmet.
- Accessory hands: gloves, without gloves.
- Accessory body: pants, and shirt, full suit, without clothes.
- Accessory feet: boots, tennis, without shoes.
- The extra accessory: control, ship, pet, without an additional accessory.

Solution

Consequently, different combinations that consider the data obtained are possible. Thus, it is necessary to deal with all possible combinations and to make this process faster. The design team used a computer tool: the Constraint Satisfaction Problem (CSP) Applet to find all combinations derived from the previous stages, resulting in 144 combinations. The process deployed in the CSP applet is for the moment out of the scope of this chapter.

Conceptual design

The conceptual design proposed in this section satisfies all the user requirements. In fact, there are several potential solutions produced by the CSP solving process. Only one is depicted in this section (Figs. 2.13 and 2.14).

Fig. 2.13 Conceptual design of one of the solutions

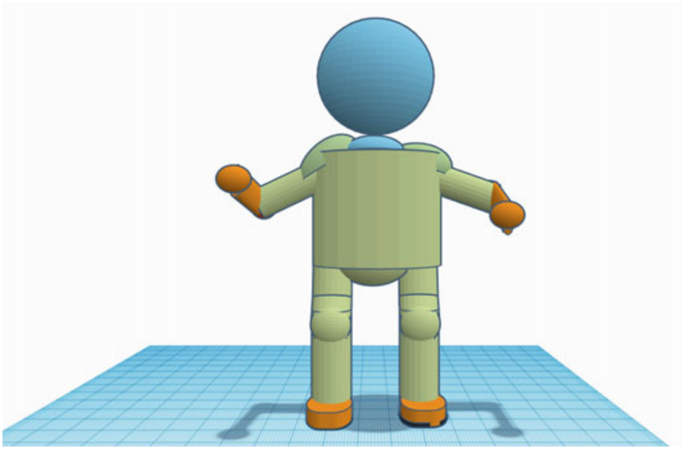

Fig. 2.14 3D model prototype of one of the solutions

2.7 Recommendations

The process applied in the conceptual design of this toy can be deployed in other products. The case study suggests formulating the ideal system in step two because it gives some guidelines to identify what resources the product can consider later in the problem-solving process. Then, the team should formulate and solve all contradictions and propose potential solutions. The use of TRIZ and CAI are useful in the conceptual design of customized products with the purpose to avoid the presence of harmful effects or negative effects in the technical functions of the system.

2.8 Conclusions

Customization is a strategy that results in increased customer satisfaction through the delivery of products focused on their expectations and needs. However, there are some problems in the customization of products such as the configuration of the item or the potential conflicts among components that must be solved before making the product available to the market. Therefore, in the conceptual design, it is essential to apply some tools that analyze the customer requirements and then assist the decision-making process. Finally, the results obtained were as follows:

- The identification of the historical background of the product to be customized (case study) to know the perspective of technological development on patent databases.
- The combination of TRIZ and CAI made it possible to formulate or reformulate a product design that involved the client and his needs from the early stages of the design.
- The integration of TRIZ and CAI is a field of opportunities, especially for product customization in the conceptual design phase.

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Chapter 3
Application of Design Thinking and TRIZ Theory to Assist a User in the Formulation of an Innovation Project

Hugo Domingo García-Manilla

Abstract The main limitations of Design Thinking lie in its high subjectivity, the presence of psychological bias, and the lack of focus in the idea generation phase. Furthermore, it does not offer strategies or techniques for the specific solution of the inherent problems in the design process, aspects that the theory of inventive problem-solving or TRIZ can cover by approaching the problem in the form of a contradiction. The employment of TRIZ within the Design Thinking process has the potential to facilitate the generation of alternative solutions through the principles of separation or the contradiction matrix. On the other hand, TRIZ does not consider to a large extent the user for whom one designs, an aspect that is fundamental in design thinking. Consequently, the combination of the capacities of both approaches can generate a complementary structure to approach the design process. This paper describes a basic structure to combine the best characteristics of both approaches to channel creative thinking and efforts during the development of an innovation project.

Keywords TRIZ · Design thinking · Product design · Innovation

3.1 Introduction

If a company wants to maintain its competitive position in the present market, it must make an effort so that its products and services meet the needs and desires of consumers. The success of a product (either manufactured or service) in the market will depend on the correct identification and assimilation of these requirements.

Therefore, the manufacturer's starting point for the design of a new product or the modification of an existing one lies in the capacity it presents for identifying present and future market demands with the highest possible degree of accuracy.

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Therefore, the organization must be agile and efficient enough to capture what are the needs and requirements of the users and materialize them in a product to satisfy them. The Design Thinking (DT) methodology starts from a deep study and analysis of the user when they are interacting with the product, this process is called: Empathy, and its purpose is to detect the problems that it presents during that experience, to later enunciate a series of probable solutions and finally, select the one that most efficiently solves the problem.

Despite the usefulness of DT, this approach does not propose specific tools to deal with problems that are always associated with the design process. A method based on the evolution of technology offers a series of concepts and tools to solve problems: the Theory of Inventive Problem Solving (TRIZ). Despite its ability to model and solve problems, TRIZ does not have in its structure a tool to identify market needs. This task is based on an individual's experience and knowledge of using other tools.

Therefore, both methods are complementary: DT produces valuable information to guide the design effort, while TRIZ provides an effective and repeatable toolbox for problem-solving. Thus, this paper proposes a framework to combine the advantages of both methods and demonstrate the usefulness of this combination to provide new resources with the potential to be used in the design of new products.

This chapter proposes five sections, the first one describes the design thinking methodology process, in which its basic concepts are cited, accompanied by an analysis of its state of the art, to observe how DT has been used during the design and development of new products or the modification of existing ones in different organizations.

Subsequently, a brief analysis of the Theory of Inventive Problem Solving (TRIZ, by its Russian acronym) describes the basic concepts, explores its usefulness in problem-solving processes, and underlines the bases that support it. Also, a review of the state of the art is presented to observe how it is used during the product design process and the resolution of engineering problems.

Once the reader becomes familiar with the concepts, we proceed to describe the integration of Design Thinking (DT) with the TRIZ theory, indicating which elements of TRIZ will be incorporated into the different phases of DT.

Finally, the last section proposes a case study to observe the feasibility of the DT+TRIZ integration, and its applicability during the design of new products, the transformation of existing ones, and the resolution of problems in the industry.

3.2 Innovation

An innovation is the introduction of a new, or significantly improved product (good or service), a process, a new marketing method or a new organizational method to the market and society (Oslo Manual 2005). In order for a business organization to develop a new product or improve an existing one within its portfolio, there are various design methodologies that establish a series of procedures, tools, and techniques to generate new proposals. Below, two of these design methods are exposed, the design thinking model, which has a strong position in the business ecosystem to design products and their easy applicability, and the TRIZ theory, which stands out in solving engineering problems, recognized for the high training that users of this methodology must have.

3.3 Design Thinking

3.3.1 Definition

It is a method of designing products, using the designer's way of thinking, which uses a type of unconventional reasoning in the business world, that is, deductive thinking. Therefore, the designer seeks the formulation of questions through the understanding of phenomena. In other words, questions are generated that must be answered from the information gathered during the observation of the universe surrounding the problem. Therefore, when thinking deductively, the solution does not derive from the obstacle: more precisely, it fits into it (Vianna 2016). There is a wide debate in the design community about who was the first author to coin the term "Design thinking", where a group attributes it to Herbert Simon (1978 Nobel Prize in Economics), and on the other hand to Peter Rowe, a renowned professional in the field of architecture and urban design, he served as a professor at Harvard University and published the book: Design Thinking in 1987. However, its massification and positioning as a methodology for product development and improvement are due to Tom Kelly and Tim Brown, co-founders of the international design and innovation consultancy IDEO, who disseminated the five-stage process (empathy, problem definition, ideation, prototyping, and evaluation) best known in entrepreneurship and design ecosystems.

3.3.2 Stages that Make Up the DT Process

The DT model of the Design Institute of Stanford University, the most widespread in the business and entrepreneurship ecosystem, is described below (Hasso Plattner Institute of Design at Stanford 2009):

Empathy: Empathy is the foundation of DT. To achieve this, it is necessary to carry out the following actions: (1) Observe the behavior of users in the context of their lives while using the product. (2) Interact with users and interview them through scheduled meetings and "intercept" them. (3) Experience what the user experiences while interacting with the product. The designers of the solution must understand people to transform this observation into knowledge and later into a product. The designer interprets and infers information about the meaning of the data obtained to discover ideas or perceptions. These perceptions channel the creative effort to generate solutions that satisfy their needs, requirements, and desires.

Definition of the problem: This stage summarizes the findings gathered through empathy and defines a specific and relevant problem. The objective is to define the problem or problems that the team must address and establish the evaluation criteria. It is also at this stage that the work team formulates design constraints and plans the evaluation metrics to validate a concept.

Ideation: This stage requires creative effort. The team needs to direct their creative efforts to come up with concepts that solve the design problem. Traditionally, this stage uses psychological tools such as brainstorming, six thinking hats, and lateral thinking, among other available techniques. The ideation stage is the transition from problem identification to the exploration of potential solutions. The team leverages collective perspectives, strengths, and creative effort.

Prototyping: A prototype is the first representation of what the product will look like, it can be a physical structure, sketches on paper sheets, simulations in software, and it can even be represented by means of a role-play or a recreation of some situation if we refer to a service. Its objective is that the development team can put it to the test and, most importantly, that it be provided to the user in order to be manipulated by them.

Evaluation: Qualification and quantification of the prototype, its performance is rated in the context of the user, feedback is collected from the user, in order to determine if their needs and requirements have been met or otherwise repeat the process in order to generate another proposal.

3.3.3 Design Thinking: State-of-the-Art Review

By analyzing the state of the art of Design Thinking, the following conclusions arise about this design approach:

One of the main strengths of design thinking is the ability to communicate ideas and create value proposals with multidisciplinary teams (Geissdoerfer et al. 2016; Brown 2009). Design Thinking has been increasingly recognized as a promising asset for fields other than design. It gained attention in the sectors of business, leadership, and management, as an option to deal with the growing complexity of the market and to be used as a source of innovation and commercial success (Davis 2010; Dorst 2011; Fraser 2007).

Design Thinking allows anyone without design experience to create solutions to everyday challenges. These solutions may be products, services, environments, organizations, and modes of interaction. The design team converges to transform the collected information into meaningful ideas (Shapira 2015). Principles that characterize DT according to Glen (2015):

- It is centered on the being. It tries to develop new knowledge about the problems faced by users in everyday life. It is necessary that the designer puts aside preconceived ideas and be willing to observe to define which problems deserve further investigation. It develops empathy.
- Observation. To understand human needs, the DT emphasizes observation that at the same time leads to empathy, understanding, and analysis. The purpose is to obtain an understanding of the user's requirements.
- Display. The approach used to make information meaningful. It takes advantage of empathy and intuition.
- Prototyping. The idea is represented with the purpose of obtaining feedback and learning. To generate many disposable prototypes, in the fastest and cheapest way possible.

According to Volkova and Jakobsone (2016), one of the most effective strategies to improve competitiveness is achieved by creating new products, with meaning, with added value and through the personalization of products taking into account the following aspects:

(a) The understanding of the identity and culture of the user.
(b) The requirements currently requested.
(c) Future trends.

DT has become an integral part of the innovation process. In fact, it plays a strategic role in the generation of value through the creation of ideas that respond better to the expectations and needs of consumers.

Design thinking with its broad and generic applicability provides an efficient method for the creation of value-added products effectively (Brown 2008); justifying in this way their ability to be integrated into other techniques, such as TRIZ.

DT involves solving complex problems that require curiosity, imagination, and creativity to generate, explore, and develop possible solutions, with value for the final user (Dorst and Cross 2001). It offers to companies the ability to transform products, services, processes, and strategies, where the last one determines new forms of value (Brown 2008).

DT defends the importance of empathy with the consumer. To develop good solutions, teams need to understand their users; how they think and what they feel about the problem that the group seeks to solve. DT offers a set of techniques about how to develop the ability to become empathetic with the users. It suggests the innovation teams to immerse themselves in the lives of their users and observe how they interact with the products they want to improve. By watching, listening, and collecting stories, they can capture unexpected ideas or longings. In line with DT's approach, innovation teams need to know their users and care about them and their lives to create meaningful products (Brown 2009).

The flexible application of Design thinking provides an effective method for creating value-added products effectively (Brown 2008). However, its flexibility of application implies that the expert who applies the DT is in need of solving problems outside his area of expertise. Consequently, it is necessary to aggravate the

DT deployment process with a method capable of formulating and solving problems in multiple domains. The Theory of Inventive Problem Solving (TRIZ) has this competence. The next section explores the use of TRIZ in the innovation process.

3.4 Theory of Inventive Problem Solving (TRIZ)

3.4.1 Definition

The TRIZ theory is an empirical, constructive, qualitative, universal methodology for generating ideas and solving problems, primarily when projecting engineering systems, on the basis of contradiction models and methods to solve them that were extracted from known inventions (Orloff 2012). TRIZ is a systematic, knowledge-based, and human-oriented methodology of the inventive problem-solving (Savransky 2000). TRIZ is the Russian acronym for the Theory of Inventive Problem Solving, developed by Genrich Altshuller. Its objective is to solve inventive problems and the intensification of creative and technical thinking. An inventive problem is the one that contains at least one contradiction (technical or physical), in which the conditions of the problem do not allow negotiation or compromise between the different parties to the conflict (Cortés 2003).

3.4.2 Basic Concepts of TRIZ

Contradictions: It is a situation that emerges when two opposite demands must be met in order to provide the result required. A contradiction is argued to be a major obstacle to solve an inventive problem, two types of contradictions are known in TRIZ: (1) Engineering and (2) Physical (Chechurin 2016). (1) Physical conflict: It is a situation that emerges when a certain attribute of a material object (represented as a substance or a field) must have two different (or opposite) values at the same time to provide the result required. An attribute can be a physical parameter, aggregate state, location, etc. (2) Engineering contradiction: It is a situation that emerges when an attempt to solve an inventive problem by improving a certain attribute (parameter) of a technical system leads to an unacceptable degradation of another attribute (parameter) of the same system.

According to TRIZ, often the most effective inventive solution to a problem is the one that overcomes some contradictions. A contradiction shows where (in the so-called operative zone) and when (in the so-called operative time) a conflict happens. Contradictions occur when improving one parameter or characteristic of a technique negatively affects the same or other characteristics or parameters of the technique (Savransky 2000).

Contradiction matrix: It is a matrix that provides systematic access to the most frequently used inventive principles to resolve a specific type of technical contradiction. In the contradiction matrix, a specific type of technical contradiction is selected by the predefined typical engineering parameters (Chechurin 2016).

The separation principles: Often a subsystem must perform contradictory functions or operate under incompatible requirements, in TRIZ such a situation is known as a physical contradiction (Savransky 2000). There are four separation principles for the resolution of physical contradictions: (1) Separation in space, (2) Separation in time, (3) Separation under conditions, and (4) Separation between the whole and its parts.

The 40 Inventive Principles: It is a set of generic solution proposals applicable in various industries. They are tips for finding highly creative and patentable solutions for solving your technical contradictions, that is, the problem in question.

Ideal system: The "ideality" of a system is the measure of how close it is to the perfect system. The perfect system (called the "ideal final result" in TRIZ) has all the benefits the customer wants, at no cost, with no harmful effects. So, a system increases ideality when it gives you more of what you want or less of what you do not want, does it at a lower cost, and usually with less complexity (Rantanen and Domb 2008). The Ideal Final Result (IFR) is the absolute best solution to a problem for the given conditions (Savransky 2000).

Resources: According to TRIZ, are things, information, energy, or properties of the materials that are already in or near the environment of the problem. If they can be used directly or modified to make them useful, the problem will appear to have solved itself. Think of the resources as the reserves they are invisible at first because we are accustomed to not seeing them when we look at the problem situation, but we can mobilize these reserves to solve the problem (Rantanen and Domb 2008). Resources can consequently be grouped in accordance with the following descriptions: (1) Natural or environmental resources, (2) Time resources, (3) Space resources, (4) System, (5) Substance resources, (6) Energy/field, (7) Information resources, and (8) Functional (Savransky 2000).

Psychological inertia: The resistance to thinking in a new way. By analogy to physical inertia, thoughts continue in the same pattern unless disrupted by a force.

3.4.3 TRIZ Benefits

Good solutions have several common features. The good idea does the following:

- Resolves contradictions
- Increases the "ideality" of the system
- Uses idle, easily available resources
- In addition to their everyday meanings, these words have specific technical meanings in TRIZ.

By working with the TRIZ concepts, you will learn to apply them to your problems, develop good solutions, and select the best solutions from all that are proposed (Rantanen and Domb 2008). TRIZ is unique because using the techniques relatively small number of easily understood concepts and heuristics (supported by effective knowledge databases), one can solve problems of any of the classes (Savransky 2000):

1. Improvement or perfection of both quality and quantity (considered Contradiction Problems in TRIZ)
2. Search for and prevention of shortcomings (Diagnostics)
3. Cost reduction of the existing technique (Trimming)
4. New use of known processes and systems (Analogy)
5. Generation of new "mixtures" of already existing elements (Synthesis)
6. Creation of fundamentally new technique to fit a new need (Genesis).

Perhaps in the twenty-first century, an additional component—the maximum speed of development and introduction of next-generation products will determine global economic leadership. If such is the case, then TRIZ takes on even more importance because it enables its practitioners to quickly obtain very high-quality and even breakthrough conceptual Solutions and then effectively remove technical obstacles in implementing the solution (Savransky 2000).

3.4.4 TRIZ: State-of-the-Art Review

A review of the literature about the benefits that the Theory of Inventive Problem Solving confers to the innovation process, its ability to be combined with other techniques, and its role in the New Product Development process.

TRIZ is a different method to conceive new products and processes that use various tools that propose several ways to propose inventive solutions (Altshuller 1999; Vaneker and Van Diepen 2016). It is a problem-solving approach strongly based on the concept of "Contradiction" using specific techniques to solve them (Fiorineschi et al. 2018).

TRIZ is compatible with the solution of problems, prevention of failures, and incidents, management, the creation of new products/services, the definition of commercial concepts, and the resolution of administrative conflicts. Therefore, it contains a set of tools to be conveniently selected, according to specific needs (Vaneker and Van Diepen 2016).

Creativity is the ability to generate new and useful ideas to overcome limitations in the generation phase of solution proposals, (Eppinger and Ullman 2007), as well as, (Ilevbare et al. 2013) suggest the application of specific methods and/or tools to support the idea generation stage. One of these "assistants" to creativity is TRIZ, which is considered to support designers in the generation of creative solutions.

3.4.5 Reason for DT+TRIZ Integration

After analyzing the strengths and weaknesses of each of the methodologies mentioned above, it was demonstrated that there is room for improvement to integrate the TRIZ theory into the DT process. The objective of the integration is to assist a user, a team of designers or a business organization in the formulation of innovation projects to design new products or improve existing ones by combining the best characteristics of both methods. Therefore, it is feasible to propose a framework with which products can be developed or improved through a five-stage process typical of DT (empathy, problem definition, ideation, prototyping, and evaluation) and the fundamental concepts of TRIZ, which are intended to guide a team or individual in the process of solving the intrinsic problems generated by the design process and thus channel creativity, imagination and thought processes of users.

After identifying the main contributions of each method, Table 3.1 summarizes the advantages of each approach and its complementarity.

As shown in the previous table, both methods complement each other to cover their deficiencies, DT benefits from TRIZ to identify, define, and model a problem, it provides an efficient toolbox for the detailed resolution of these problems, on the other hand, TRIZ benefits from DT to identify the requirements, needs, wishes, and emotions of the user for whom a product is being designed or improved, likewise, it guides the design process in an organized way through its five stages of easy interpretation and execution. Consequently, a framework is obtained to channel the thinking and creative effort of the development team toward the design of solutions that satisfy the user or consumer.

In conclusion, it can be mentioned that the complementarity of both methods allows the design of a framework with highly technical and humanistic characteristics, which efficiently directs intellectual capital during the design process, suitable to be adopted by some business organization or individual, that has as objective the design of new products or the improvement of an existing one in order to satisfy the end user.

Table 3.1 Complementarity between TRIZ and DT

Advantages	DT	TRIZ	DT+TRIZ
It identifies a user's requirements	Yes	No	Yes
It models an innovation problem	No	Yes	Yes
It proposes tools to solve problems	No	Yes	Yes
It offers a framework to guide the design	Yes	No	Yes
It subjects the proposed solution to evaluation	Yes	Yes	Yes
It contemplates the possible evolution of a product in the future	No	Yes	Yes
It can be used by users without design experience	Yes	No	Yes
It gives meaning to the products that are being designed	Yes	No	Yes
It prototypes to evaluate the proposed solutions	Yes	No	Yes

3.5 DT+TRIZ Framework

Figure 3.1 presents which foundations of the TRIZ theory are integrated into a certain stage of the Design Thinking model.

3.5.1 Description of the Framework DT+TRIZ

Below, the structure that makes up the DT+TRIZ framework is explained, which consists of the five stages of DT with TRIZ foundations integrated throughout the process, which aims to guide a user or team of product design in the formulation of an innovation project.

Stage 1: Empathy

The first stage of the DT method is called "Empathy" and is the basis of the entire design process since its primary objective is to understand the user for whom a product is designed. It is of utmost importance to carry out a wide and efficient investigation. Since the more information about the user, client, or consumer for whom the product is being designed is obtained, the greater the amount of material that is available for the generation of a solution that meets their needs, wishes and requirements will be.

This stage is also known as "Immersion" since the user of this framework (the designed or development team) has fundamental tasks to manipulate and experience

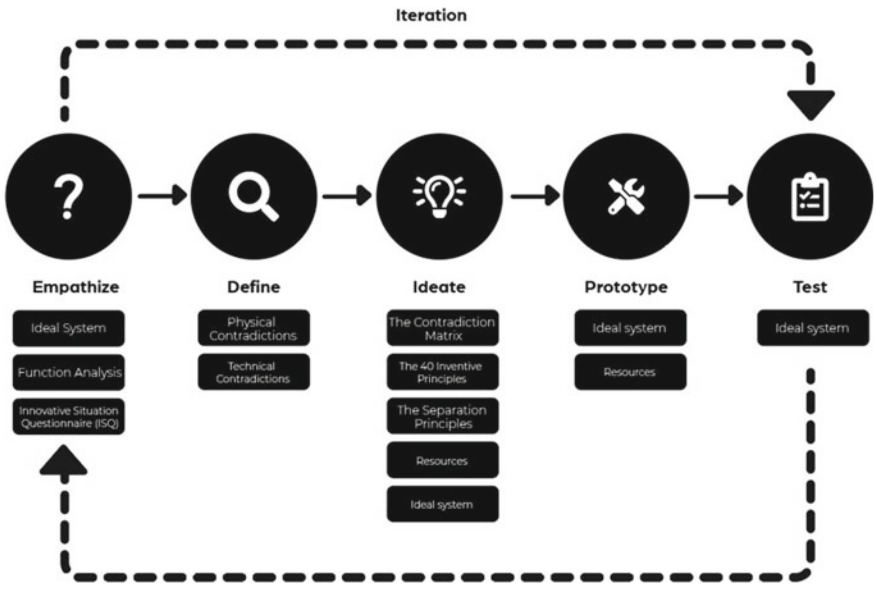

Fig. 3.1 DT+TRIZ framework

the product to be improved, as well as to try to get to know the users or customers of the product to understand their problems, requirements, emotions, and wishes. The elements of the TRIZ theory that are integrated into this section are: (1) Ideal system, (2) Functional analysis, and (3) Innovative situation Questionnaire (ISQ).

The objective of this section is to discover if the user or customer experience with the product is positive or negative, the context, the environment and routine in which they use the product. Furthermore, to observe if the user strictly follows the recommendations or has found situations to use it in a different way.

The methods used in the empathy stage can be classified by the type of information that can be collected: qualitative methods (observation, interviews, group dynamics) and quantitative methods (surveys and questionnaires) (Garreta and Mor 2010).

Results of Stage 1

The objective of this stage is to obtain user information in a concise way: tastes and preferences, environment in which they operate, routine, requirements, and desires. Knowledge about users, their contexts of use, objectives, and attitudes are essential for a user-centered design (Garreta and Mor 2010).

When implementing the ideal system concept at this stage, it is sought that when the user is describing their experience with the product or in what way they imagine the product does not exist (new product design), they should mention what elements, characteristics, and benefits that product must present so that it is 100% satisfied, that is, what functionalities and capabilities the product must possess in order to solve its problem or requirement.

To guide the interview with the user for whom it is being designed, the innovative situation questionnaire (ISQ) will be used. For the purposes of the practical case presented in this chapter, the version of the company Innovation Management and Sustainable Technologies, an innovation consulting firm, (IMST 2020) will be used. This tool is intended to effectively obtain the following information from the user: (1) Information about the system (product), (2) Information about the problem situation (with the product), and (3) Information about changes in the system (product). To reinforce Sect. 3.1 of the ISQ, the functional analysis will be used, which consists of describing the current (or desired) structure of the product and its way of operating.

Stage 2: Definition of the problem

The second stage of DT is called "Definition of the problem". In this section, the development team already has a large amount of information collected because of their interaction with the user or client in the first stage. It is here where one proceeds to analyze the data obtained in order to understand them and determine what inconvenience the user presents with the current product and the reason why their needs and requirements have not been met so far.

The elements of the TRIZ theory that are integrated into the second stage of DT are the physical and technical contradictions of the system. To efficiently delimit the needs and requirements of the user, the format is used to identify the characteristic that must be improved, in which: (1) The product is named in the form of a technical system, (2) The primary objective is defined of the system, (3) The parts and functions that make up the system are listed, (4) It describes how the system operates, and (5) It determines the characteristics that must be improved or eliminated. Similarly, the format for the formulation of the contradiction is used, which aims to guide the user to identify the properties that improve and worsen during the development process (Cortés 2015). The result is the identification of the physical or technical contradiction that will have to be resolved in the third stage of the process (Ideation).

Results of Stage 2

The main objective of this section consists of the correct identification of the physical or technical contradiction that the system (product) presents, with the support of the format for the identification of the characteristic that must be improved. The aspect or property of the product that must be resolved or modified for the user's satisfaction will be indicated.

Subsequently, through the format for the formulation of the contradiction, the characteristics that worsen during the process will be identified to achieve the property or characteristic that the user wants, in this way, the problem may be posed in the form of a technical contradiction, converting these characteristics or properties in technical parameters, which are required in the next stage (Ideation).

Stage 3: Ideation

The third stage of DT is ideation, it is in this section that a series of processes will be carried out to generate proposals for solving the problem, which was established in the previous stage. In this stage is where the greatest number of elements of the TRIZ theory accumulate among the five phases, in order to channel the thinking and creative efforts of the development team in the search for the solution to the problem.

The first concept of the TRIZ theory that is incorporated into the third stage of the DT is a contradiction, if in the previous stage (Definition of the problem) it is determined that the contradiction is physical, the separation principles are used in order to generate a solution proposal. There are four types: (1) Separation in space, (2) Separation in time, (3) Separation under conditions, and (4) Separation between the whole and its parts (Savransky 2000). On the other hand, if it is determined that the contradiction is technical, the matrix of technical contradictions is used, which consists of a tool that provides systematic access to the inventive principles used to resolve a specific type of contradiction (Souchkov 2018). The vertical elements of the matrix are the engineering parameters that need to be improved, while the horizontal columns contain the engineering parameters that may be affected or negatively degraded as a result of the improvement of the former, the numbers in the cells of the intersection guide the solution strategies (Savransky 2000), these elements are known as inventive solution principles, which make up a collection of 40 principles developed by Genrich Alshuller, the founder of TRIZ, the product of extensive studies analyzing thousands of inventions (Souchkov 2018).

In this section, the identification of the resources of the system (product) is carried out in the same way, according to Savransky (2000), these are categorized as follows: (1) Natural or environmental resources, (2) Time resources, (3) Space resources, (4) System resources, (5) Substance resources, (6) Energy resources, (7) Information resources, and (8) Functional resources. Their proper identification plays a relevant role during the design process since they can be used and generate a solution proposal to the problem. With these TRIZ tools, it is sought to best direct the creative effort of the development team in search of the ideal system to satisfy the user.

Results of Stage 3

The objective of this stage is to come up with solution proposals to resolve contradictions, make the best use of the resources available to the system and thus generate a product with the characteristics established by the ideal system, and therefore, satisfy the user.

In this section, four to six inventive solution principles will be identified (out of the 40 that exist) that aim to serve as a guide in the generation of solution proposals or system of improvement. Normally, a principle is retained to apply in solving the problem, however, the necessary ones can be used and even combined to develop a better proposal. Likewise, the system is carefully analyzed and it is determined with which of the 8 types of resources we can support ourselves to implement the previously selected solution. The entire ideation process aims to achieve the ideal system and thus satisfy the user. To determine which is the best solution among the different proposals that arise in this stage, stages four (prototyping) and five (evaluation) are required, which are explained below.

Stage 4: Prototyping

The fourth stage of DT is that of prototyping, which consists of the materialization of the proposals generated in the previous stage (ideation). If the system is a tangible asset, the device can be recreated using various materials (plastic, wood, cardboard, etc.) and even employ technology, such as 3D printing, while, if it is an intangible asset, such as services, role plays, storyboards, mockups, etc., can be used. The prototypes are provided to the user or client with the aim of manipulating and interacting with them in their daily context, to obtain feedback about the system. This should be built using resources and seeking to materialize in the best possible way the ideal system, TRIZ concepts that are part of this section of DT.

Results of Stage 4

The main objective of the fourth section is to take the solution proposals generated in stage 3 to a physical plane, experiment, and analyze their operation and performance, as well as to capture the reaction of the user or client and obtain feedback and flow of ideas.

Stage 5: Evaluation

The fifth stage of the DT is the evaluation stage, where the goal is to receive feedback from the client or user while interacting with the prototype. Thus, it will be determined whether the problems present in the system have been resolved and therefore satisfy the needs and requirements of the users, otherwise, another proposal must be presented to the user from among the various options generated in the third stage (Ideation), considering that the entire DT model is iterative, the process can be repeated as many times as necessary until the user or client is satisfied with the product provided, which in short, refers to approaching or reaching the ideal system, the TRIZ theory concept related to this last stage of DT.

Results of Stage 5

The main objective of this section can be summarized as determining whether or not the requirements, desires, and needs of the users for whom it is being designed have been satisfied, if the answer is positive, the product design process is concluded, otherwise, an iteration is carried out between the whole DT process as many times as necessary to get closer or achieve the ideal system established by the user and the design team from the first phase (Empathy). Qualitative and quantitative techniques are employed to evaluate the proposals.

3.5.2 Results of the DT+TRIZ Integration

The state of the art showed that the integration of DT and TRIZ is feasible. After analyzing the advantages and limitations of each tool, its complementarity was determined. DT provides TRIZ with accurate information about the requirements and wishes of the users for whom it is being designed. It offers a framework to guide the design process, even to be carried out by users with no design experience. In addition, it endows the product with significance to make it more attractive to the user. Consider prototyping to materialize the proposed ideas and thus facilitate interaction with the user. The proposals generated are submitted for evaluation to obtain feedback, and if necessary, to return to previous stages of DT, and thus to improve the prototype.

On the other hand, TRIZ gives DT the possibility to formulate a problem in the form of a contradiction. By implementing this strategy, it is possible to deploy the TRIZ toolkit to solve this kind of problem effectively. Therefore, DT sets a process to design products and establishes the base, which is the description of the user for whom one works, while TRIZ provides the necessary tools to channel the creative effort of the design team during the generation of potential solutions.

3.6 Case of Application: A Domestic Electrical Outlet Case for a Blind Person and Visual Weakness

The following case study shows how the DT+TRIZ framework was applied to make a proposal for improvement in a house-room electrical contact.

Stage 1: Empathy

In this first step, the Innovation Situation Questionnaire (ISQ) is useful to acquire valuable information and provides a broad perspective of a technical system (Terninko et al. 1999). The ISQ is a guide for obtaining information from the user, given its extensive dimension (17 questions). The next points show the information collected with this tool.

Information about the system (product/process)

– Electrical outlet (domestic): The primary useful function is to provide energy by contact. Also, to cover an electrical installation (electrical contact and general wiring of the house-room), while fulfilling an aesthetic function. The electrical system (1) provides electrical power to any device that is inserted into the holes through a plug, the case (2) has the function of covering the system and the electrical wiring and indirectly fulfills an aesthetic function (Fig. 3.2).

  The plug is inserted in the holes to provide electrical power to some devices, the case is responsible for covering and thus hiding the electrical installation and various wiring of the wall of the house-room.
– System resource: "Space" resource in the case, the case area is mostly unoccupied, and the space of the electrical contact holes uses small dimensions.

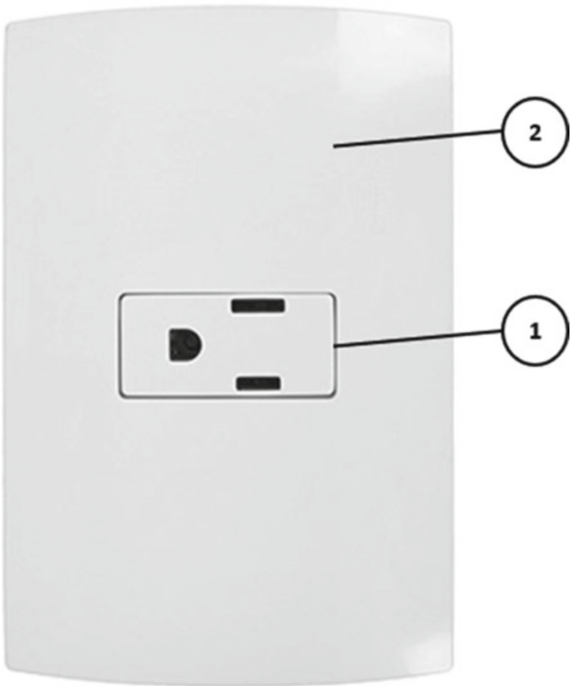

Fig. 3.2 Electrical outlet main parts

Information about the problematic situation

The area of the electrical contact holes is very small, which makes it difficult to insert a plug for a blind person, visually impaired, and even a user who simply wants to insert a plug and the place is dark or poorly lit, which turns a simple activity like inserting a pin into the socket into a cumbersome task.

Information about system changes

According to several standards (The International Electrotechnical Commission-IEC, The American National Standards Institute-ANSI, and Normas Oficiales Mexicanas-NOM, among several others), the dimensions of the contact holes cannot be increased. The adequate electrical power supply of the contact must not be compromised. The electrical installation of the house-room should not be left exposed. The electrical contact is surrounded by a case, it is possible to make modifications in the area to achieve the desired effects.

Stage 2: Problem definition

Technical contradiction

Identification of the feature to be improved

1. Name of the technical system (TS): Electrical contact outlet.
2. Define the primary objective of the TS: It is designed to provide electricity through the contact of two metal pieces, it also covers an electrical installation, and fulfills an aesthetic function.
3. List the main elements that make up the TS and their functions:
   (a) Electric contact: Transmit electrical energy.
   (b) Exterior cover: Cover an electrical installation.
4. Describe the operation of the TS: The contact transmits electrical energy to the inserted plug and through it provides power to a device. The case covers the electrical installation (electrical contact and general wiring of the house-room), fulfilling at the same time an aesthetic function.
5. Determine the features that need to be improved or removed: The case, in addition to covering the wiring of the house-room and serving as a decoration, must facilitate the insertion of the plug for blind people, visually impaired, or in a dark house-room.

Formulation of the contradiction (improvement)

Define the feature to be improved:

(a) The characteristic is: The space to insert the plug should be wider.
(b) Mention the means used to carry out this improvement: Use the case to drive the pin into the holes.
(c) Mention which is the characteristic that worsens under the conditions present in 1b: The shape of the case.

(d) Formulation of the technical contradiction: If the case of the electrical contact is modified to direct the pin into the contact holes more easily, then the usual shape of the electrical contact is affected.

The technical contradiction explains that it is necessary to increase the area of a stationary object, but the present shape does not allow this modification. This contradiction is present in the Contradiction Matrix, and then, useful in the ideation stage.

Physical contradiction

The object must be large to facilitate the insertion of the plug, but small to complain with international standards.

Stage 3: Ideation

Technical contradiction solution

This stage aims to propose possible solutions in such a way that the systems get closer to their ideal state (Altshuller 1999). It is stated that the technical contradiction refers to the fact that if the area of the system is improved, then the shape of the system worsens, so the Contradiction Matrix is used to propose a solving strategy. Savransky (2000) and Rantanen and Domb (2008) offer a detailed description of this tool (Fig. 3.3).

The technical contradiction isolates a set of inventive principles: 17, 5, 4, 7, and 28. This case study uses the Contradiction Matrix 2003 (Zlotin et al. 2003), which proposes a matrix where all rows propose at minimum four inventive principles. If a user proposes a technical contradiction that calls for a contradiction in the diagonal

Improving Feature / Worsening Feature			Physical								
			Weight of Moving object	Weight of Stationary Object	Length/Angle of Moving Object	Length/Angle of Stationary Object	Area of Moving Object	Area of Stationary Object	Volume of Moving Object	Volume of Stationary Object	Shape
			1	2	3	4	5	6	7	8	9
ysical	1	Weight of Moving Object		3 19 35 40	17 15 8 35	15 17 28 12	28 17 29 35	17 28 1 29	28 29 7 40	40 35 2 4 7	3 35 14 17
	2	Weight of Stationary Object	35 3 40 2		17 4 30 35	17 35 9 31	17 3 30 7	17 14 3 35	14 13 3 40	31 35 7 3	13 7 3 30
	3	Length/Angle of Moving Object	31 4 17 15	1 2 17 15		1 17 15 24	15 17 4 14	17 3 7 15	17 14 7 4 3	17 31 3 19	1 35 29 3
	4	Length/Angle of Stationary Object	35 30 31 8	35 31 40 2	3 1 4 19 17		3 4 19 17	17 40 35 10	35 30 14 7	14 35 17 2	13 14 15 7
	5	Area of Moving Object	31 17 3 4 1	17 15 3 31	14 15 4 18	14 17 15 4		17 1 4 3	14 17 7 4	14 17 7 13	35 4 14 17
	6	Area of Stationary Object	14 31 17 19	35 14 31 30	17 19 3 13	17 14 3 4 7	4 31 7 19		17 18 14 7	14 28 26 13	17 5 4 7

Fig. 3.3 Fragment of the traditional MRCT that indicates the principles for the resolution of the contradiction area of a stationary object versus shape

of the matrix, this problem is in fact, a physical contradiction, and thus the separation principles are the best tool to use.

Recommended Principles

Principle 17. Movement into a new dimension

a. Remove the problems of moving an object on a line with movements in two dimensions (along a plane). Similarly, the problems of moving an object in a plane go away if the object can be changed to allow for three-dimensional space.
b. Use a multilayered assembly of objects instead of a single layer.
c. Tilt the object or flip it as it should be.
d. Project images on nearby areas or on the front of the object.

Principle 5. Combining

a. Combine in a space homogeneous objects or objects intended to operate continuously.
b. Combine homogeneous or contiguous operations in time.

Principle 4. Asymmetry

a. Replace a symmetric shape of an object with an asymmetric one.
b. If the object is already asymmetric, increase the degree of asymmetry.

Principle 7. Nesting

a. Contain the object inside another that is ultimately contained in a third object.
b. An object passes through the cavity of another object.

Principle 28. Replacement of mechanical systems

a. Replace the mechanical system with an optical, acoustic, or odoriferous one.
b. Use an electromagnetic, electric, or magnetic field for interaction with the object.
c. Replace the fields.
d. Use a field in conjunction with ferromagnetic particles.

Retained principle

After analyzing the principles cited above, it is determined that principle number 5 can be applied to solve the problem. The principle consists of combining objects in a space to operate continuously.

Solution implemented

The recommendation based on principle number 5 was applied. It is proposed to modify the area of the case to give it a funnel shape. This change assists the user to facilitate the insertion of the plug. Thus, the funnel shape will direct the plug toward the electrical contact holes, achieving the continuous operation effect described in principle 5. The case fulfills its initial function of covering the electrical installation and simultaneously directs the plug to the proper position to be inserted.

Physical Contradiction Solution

The separation principle suggested: separation in space. This principle recommends:

A. Attempt to split (actually or theoretically) the key subsystem into two or more subsystems.
B. Assign each conflicting function or opposing requirement to a different subsystem.

This principle of separation suggests that the system must be divided into two or more subsystems, which means that the case, besides fulfilling its function of covering the electrical installation, should direct the plug toward the holes in the contact.

Stage 4: Prototyping

The objective of this stage lies in the materialization of the solution proposals generated in the third stage (Ideation). The developed prototypes are shown (Table 3.2, Fig. 3.4, Table 3.3 and Fig. 3.5).

Stage 5: Assessment

To evaluate the two prototypes developed in stage four and select the one that has the characteristics of the proposed ideal system (or the one that is most similar to it) and meets the requirements stipulated by the user, an assessment matrix will be used. The assessment matrix consists of a measurement instrument to assess the performance of a series of specific criteria. The criteria that will be assessed in each of the prototypes are:

– **Functionality**: The casing fulfills the objective of facilitating the insertion of the plug in the contact holes.
– **Time**: It is possible to reduce the time in which a blind user, visually impaired, or in a dark room inserts the plug into the contact holes.
– **Security**: The casing continues to perform the important function for which it is designed, that of covering the electrical installation and wiring.

The Pugh evaluation matrix (Pugh 1991) and the results obtained when evaluating the two developed prototypes are shown (Table 3.4).

As can be seen, prototype 1 obtained a score of 2, while prototype 2 obtained 3 points. The foregoing indicates that the second prototype is the one that best covers

Table 3.2 Prototype 1

Prototype 1
The first prototype consists of sectioning the casing area in the form of a funnel, with a wide opening on the upper side, which is reduced as it approaches the contact holes, to channel the plug with the sole fact of contacting the case, in this prototype the usual vertical position of the contact is maintained.
Illustration

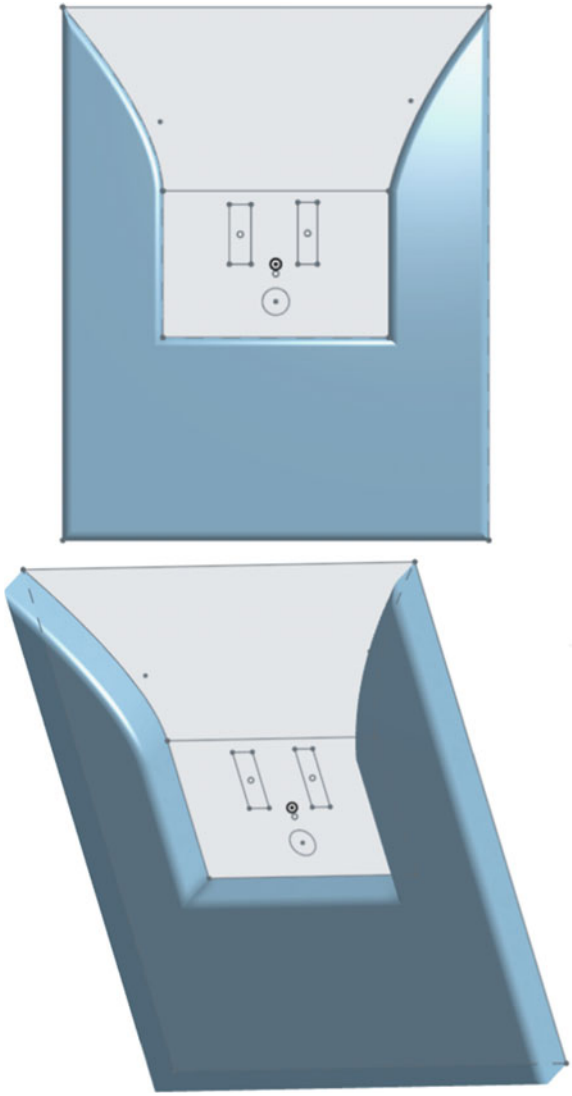

Fig. 3.4 Prototype 1, electrical contact case in vertical position

Table 3.3 Prototype 2

Prototype 2
The second prototype consists of sectioning the casing area in the form of a funnel, with a wide opening on the upper side, which is reduced as it approaches the contact holes, to channel the pin with the sole fact of contacting the case, in this prototype the usual position of the contact is modified, placing the case in a horizontal position.
Illustration

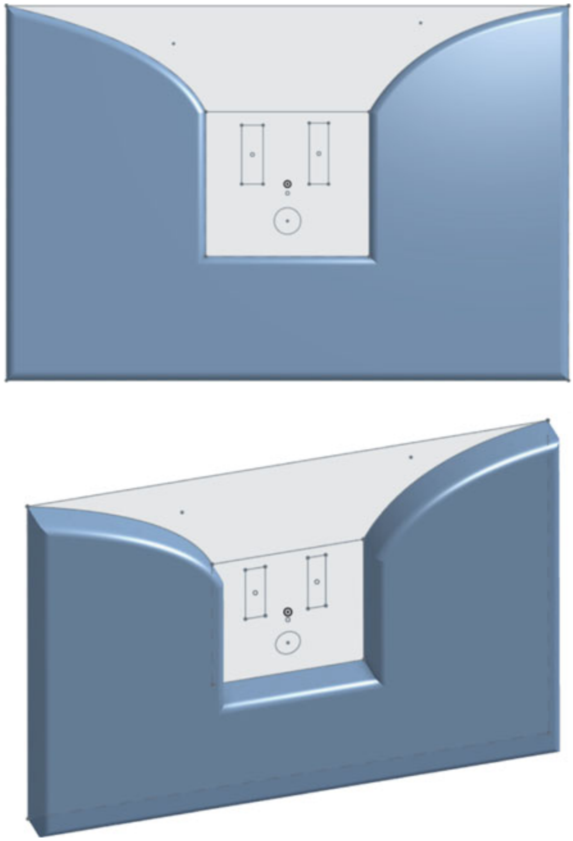

Fig. 3.5 Prototype 2, electrical contact case horizontal position

Table 3.4 Pugh matrix applied to prototypes

Criteria	Design alternative	
	Design	Design
Functionality	1	1
Time	0	1
Security	1	1
Positive sum	2	3
Negative sum	0	0
Total	2	3

the needs and requirements of the user, that is, the one that is closest to the ideal system, this being the one chosen as the final product.

3.7 Conclusions

The DT+TRIZ framework meets the objective of guiding the design process of new products and services, as well as the improvement of existing ones, being used by an independent designer, entrepreneur, or business organization, who has the initiative or commission to create a product that best meets the wishes and requirements of a user or customer. During its implementation, rambling, psychological bias, and creative blockages are reduced, increasing efficiency when generating solution proposals. Importantly, it provides the tools and elements necessary to argue why the proposed solution generated after the implementation of this framework is ideal for meeting market demands.

One aspect to highlight is the interest that the DT+TRIZ framework generated in the national and international academic community, since when it was disseminated in conferences through presentations, articles, and research stays, the topic generated interest in the attendees for the originality of integrating a methodology with highly technical characteristics such as TRIZ theory into a methodology with highly subjective characteristics, such as the DT process, which has been adopted by a large number of private companies, educational institutions, foundations, and the government to develop your products and services.

3.8 Future Work

It is contemplated to incorporate the trends of evolution into the framework to explain what the stages of development of a product will be. In this way, it will be possible to plan a family of products and to better manage its transitions.

It is considered to develop a mobile, web, and/or desktop application that contains the DT+TRIZ framework and guides the process of developing new products. Data mining, knowledge management, and artificial intelligence is contemplated for the development of this software.

Finally, it is necessary to continue disseminating this research and its respective results in scientific journals in the field of design, product design, and innovation management.

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Chapter 4
Innovation Process Workflow Approach to Promote Innovation in the Food Industry

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Abstract The economic, social, environmental and safety issues have created a global crisis and no industry is immune to its effects. The consequences of this crisis not only bring uncertainty but also the opportunity to improve. With this regard, the food industry is now facing the significant challenge of improving its innovation process during the development of new products. Products should be economically competitive, easily adaptable to changes to the shifts of the consumer behaviors, and competitive to the new market circumstances. Thus, to overcome this challenge, it is necessary to develop the capability to accelerate the new product development (NPD) process, to understand the innovation process, and to improve the capacity to solve problems inventively. In response, this research presents an approach for a systematic problem-solving process that fits within the innovation process with the aim to promote innovation in food technology. This approach has its roots in the Theory of Inventive Problem Solving (TRIZ) and the General Theory of Powerful Thinking (OTSM). The approach guides through the stages of the innovation process; describes the main phases and their sequence; and manages the knowledge, the activities, the tools, and the methodologies to support the problem-solving process. A case study related to the improvement of the spray drying technology depicts the usefulness of this approach and highlights its capabilities.

Keywords Innovation process · TRIZ · OTSM · Spray drying · Food technology

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4.1 Introduction

The new product development (NPD) process is a dynamic and continuous process of transforming ideas into innovative products (including processes and services) to meet the market demands and other social needs, creating new business opportunities. In general, this NPD process encompasses the following successive steps: Framing, Visioning, Integration, and Development. The creation and development of innovative products is always a challenge, and it is strongly dependent on the management of the innovation process. In the food industry, innovation relies on the capability to meet, in an inventive way, the actual and future technological needs. Needs such as the development of new food technological breakthroughs, to create alternative food processing methodologies, or to redesign existing products and processes are necessary. The final purpose is to satisfy the consumer demands considering different aspects such as environmental concern, cultural needs, wishes, and consumer expectations (Earle 1997; Klimczuk and Klimczuk-Kochańska 2019; Saguy et al. 2013). For this challenge, the innovation management process is a crucial component for companies. However, managing involves a complex coordination of knowledge (production and dissemination), tools, and methodologies as well as it requires the collaboration of multidisciplinary, and sometimes independent, workgroups (De Bernardi and Azucar 2020a; Flores et al. 2015a).

The innovation process in the food industry is one of the key drivers but, at the same time, it is a complex process because it is necessary to include and create a compromise between social, technology, economic, commercial, scientific, industrial, health safety, and environmental dimensions (De Bernardi and Azucar 2020b; Khedkar and Khedkar 2020). The Innovative process engineering model proposed by Penidea et al. (2013) is a first attempt to understand this multi-level process in the development of innovative food products. However, this model requires techniques, methods, and tools for its successful implementation. In one of our previous research works (Barragan-Ferrer et al. 2018), we stressed the importance of the preliminary stages of the innovation process. This early phase is focused on the problem definition, the search for creative ideas, and creating innovative solutions. These early stages are supported by traditional methods such as brainstorming techniques, lateral thinking, and morphological analysis. Unfortunately, these tools showed some weaknesses such as time-consuming due to the random search of solutions, the difficulties to search solutions in different scientific domains, and lack of systematization (Cortes Robles et al. 2009). These shortcomings lead to the development of new alternative approaches, methods, and tools to bridge this gap. The Theory of Inventive Problem Solving (TRIZ) and the Theory on Powerful Thinking (or OTSM, its Russian acronym) propose a systematic problem-solving process that fits within the aimed multi-level innovation process.

Therefore, this chapter presents a new approach for a systematic problem-solving process that fits within the innovation process with the purpose to promote innovation in food technology. In Sect. 4.2, the innovative process engineering model is presented to understand this multi-level innovation process. Then, the Theory of

Inventive Problem Solving (TRIZ) and the General Theory of Powerful Thinking (OTSM) are the cornerstones of the problems solving process of our approach are described in Sect. 4.3. In Sects. 4.4 and 4.5, the innovation process workflow model and the Innovation process workflow approach are introduced. Section 4.6 shows a case study related to the improvement of the spray drying technology using this approach. Finally, the conclusion of this research is drawn and some future research trends are presented.

4.2 Innovation Process

Extended research has been carried out to establish a generic innovation process model that can be replicated systematically across organizations to promote the discipline of innovation. One first attempt to describe and manage the innovation process are the typical linear models proposed by Brandenburg (2002), Mann (2002), or Roper (2008), for example. Yet this linear process bears no relation to reality. The process is iterative. It moves forward and backward multiple times between stages. Also, it is unclear which are the main activities. Through our experiences in innovation projects, we faced many inconsistencies using linear models, leading us to the need to find more appropriate models. Other authors consider the innovation process as a multilevel process with feedback loops in which exits a horizontal alignment between business processes and the engineering process of the enterprise (Penidea et al. 2013). Our research is in line with this last kind of models, in specific the innovative process engineering model.

4.2.1 Innovative Process Engineering Model

The research of (Penidea et al. 2013) represents the innovation process as a framework of three hierarchical levels that interact and influence each other (Fig. 4.1). These levels are:

The management level at the upper level of the hierarchy, includes all the management activities used to select and evaluate information, to make strategic decisions, and to control the activities at an operational and supporting level. This level contains four milestones that control the stream of knowledge and establish feedback loops among the hierarchical levels. For example, the resulting output of one operation phase is evaluated and the decision is taken to move on to the following operational process, to end the process , or to return to the previous processes.

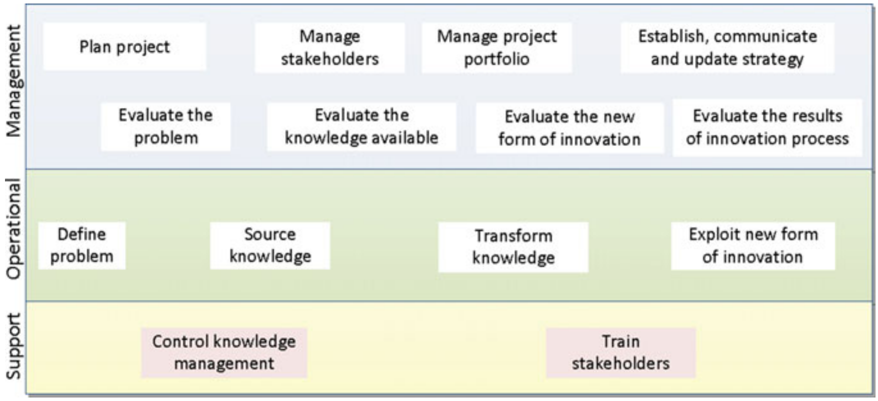


Fig. 4.1 Innovative process engineering model (Penidea et al. 2013)

The operational level is considered a knowledge transformation process. This level consists of four steps: (a) Problem definition phase is used to formulate the problem by establishing the requirements, constraints and goals, as well as harvesting initial ideas or unsolved problems to trigger the innovation process. (b) In the knowledge sourcing phase, the knowledge (internal or external) required to solve the problem is acquired from diverse sources (Roper et al. 2008). (c) In knowledge transformation, the sourced knowledge is used to propose a new inventive product (invention). (d) Finally, in the exploitation phase, the new inventive product is implemented and exploited. Also, the knowledge improved and/or acquired during the previous phases is capitalized in this last step.

Supporting level contains the activities that do not participate directly in the innovation process, but they provide resources to accomplish each phase of the operational process. Also, this level gives support to the activities at the management level.

The innovation engineering process model introduces a no linear knowledge transformation process where it interacts with the management, operational, and supporting activities. Interpreted from a business process model view, (Chaher et al. 2017) replace the four stages for the stages framing, visioning, prototyping, and developing. However, these four stages are a management interpretation of the operational stages. From our perspective, the innovation process of (Penidea et al. 2013) is similar to 9-windows operators of TRIZ representing the super-system, the system, and the subsystem of the process. In addition, the TRIZ theory could provide techniques, methods, and tools for the successful implementation of this model to support the innovation process in the food industry. Thus, TRIZ-OTSM offers an opportunity to systematize this innovation process.

4.3 TRIZ Theory and OTMS

4.3.1 TRIZ Theory

TRIZ theory, the Russian acronym for the Theory of Inventive Problem Solving, is a method of systematic thinking for solving problems inventively. It was proposed by Altshuller based on the analysis of thousands of inventive patents in which he observed that only 2% of all patented solutions were "real new discovery", such as LASER. The other 98% were, in fact, only transpositions or adaptations of technological or physical principles already known in other domains of technology, but implemented differently (Altshuller 1984; Negny et al. 2012). Another conclusion of his analysis was that technological systems evolve through the elimination of contradictions that prevent their development (Altshuller 1996). Thus, he defined that those inventive problems have at least one contradiction that expresses a conflict between two parameters or requirements of a technological system that are mutually exclusive, but they must be associated to achieve the desired result (Savransky 2000). Considering all these findings, TRIZ proposes a systematic inventive problem-solving process with the following elements:

1. A set of concepts for analyzing and representing inventive problems (contradiction, most desired result, and ideality, for example).
2. A collection of methods, tools, and meta-knowledge database among them: substance-field analysis, the contradiction matrix, the 76 standard solutions, and the effects database.
3. A set of patterns of evolution of technical systems that are independent of a specific technological domain.

The TRIZ theory offers several advantages, compared with intuitive and other analytical methods. For example, TRIZ can overcome the barriers between different technological domains. To achieve this benefit, TRIZ provides access to various solutions, best practices, and strategies that have been successfully applied to solve similar inventive problems in the past (Orloff 2006; Rantanen and Domb 2010). Furthermore, TRIZ theory can be used as a common language among the participants from different scientific domains to ease the communication and the interchange of ideas during the innovation process, as suggested in Flores et al. (2015a).

However, the TRIZ theory also presents some disadvantages for its use. One significant limitation is the difficulty of solving complex multidisciplinary problems (Khomenko et al. 2007). The reason for this restriction is that the TRIZ theory uses several engineering elements to solve technical problems. Therefore, the TRIZ theory reaches its limits when it is necessary to address multidisciplinary problems such as in the food industry. Moreover, the TRIZ theory lacks some tools to formalize in a clear and structured way the initial analysis of the problem situation. Another drawback is that it can only manage one contradiction, but in a multidisciplinary problem, several contradictions could arise. To overcome these drawbacks, Khomenko et al. (2007)

proposed the development of the General Theory of Powerful Thinking (Russian acronym: OTSM).

4.3.2 The General Theory of Powerful Thinking (OTSM)

Since its creation, the TRIZ theory has been in a continuous development process, characterized by different cycles or waves of evolution that started with a simple technique to solve inventive problems until a complete novel approach to manage complex interdisciplinary problems known as the General Theory on Powerful Thinking (OTSM). OTSM consists of four networks: (1) The problem network; (2) The contradiction network; (3) The parameter network, and (4) The general parameter network. These four networks are effective to manage an inventive resolution of a complex problem. OTSM also proposes four technologies to manage the problem-solving process: (1) The new problem technology, (2) The typical solution technology, (3) The contradiction technology, and (4) The problem flow technology (Cavallucci and Khomenko 2007; Khomenko and Guio 2007).

OTSM offers some benefits compared to classical TRIZ. For example, OTSM facilitates the understanding of the problematic situation through the collaboration with different experts. Also, it can interact and adapt the knowledge and information according to the specific type of problem to solve. Another difference is the possibility to formulate and solve complex problems with several contradictions. Therefore, considering the advantages of OTSM and the TRIZ theory to address inventive problems, rather than use these two methods separately, they are unified to create a general method for inventive problem solving: the OTSM-TRIZ method. In this combined approach, the networks and technologies of OTSM, and the methods, tools and concepts of classical TRIZ are harmonized with the "problem flow network" to manage a permanent flux of problems (Cavallucci and Khomenko 2007; Khomenko and Guio 2007). Hence, the integration of OTSM-TRIZ with the Innovative process engineering model is the basis for developing our approach to assist the innovation in food technology. The next section describes this approach in detail.

4.4 Innovation Process Workflow Model

The innovation process workflow model (Fig. 4.2) allows the representation of the innovation process that evolves continuously. The model incorporates simultaneously, on the one hand, the multilevel innovation process model to be used for managing the flow of the interconnected network of elements during the innovation process. On the other hand, the set of methods and tools of OTSM-TRIZ is dedicated to managing the problem-solving process at the preliminary stages of the innovation process. Its design is based on acquired experience in food projects in

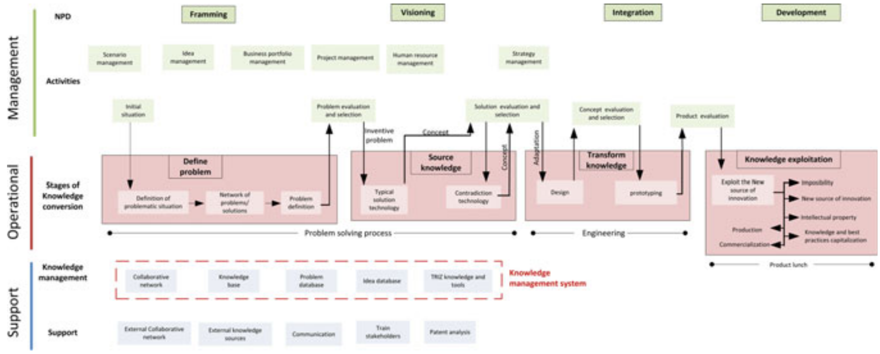


Fig. 4.2 Innovation process workflow model

which different innovation processes and the creative tools of TRIZ were implemented. The next points describe in-depth the key features and each phase of the workflow.

4.4.1 The Management Level

The main functions of the management level are related to the activities of initiating, executing, controlling, evaluating, and ending the innovation process. For example, this level includes two sets of activities: the first group used to implement the strategies and support the innovation project (e.g. project planning, portfolio management, team management, etc.); the second one, the activities to make "high-level" decisions with the outputs at the operational level.

At this level, the innovation process is integrated into four stages of the new product development process:

- The framing stage: the analysis with the market pull strategy or technology push strategy helps us to set up the innovation opportunity. This opportunity is defined as the initial situation (motive or purpose to innovate) giving rise to a new project. During this stage, the problem(s) is (are) defined.
- The visioning stage: the defined problems in the earlier stage are selected and evaluated to start the problem-solving process. Then, in the end of the stage, the proposed solutions during this process are evaluated and the most promising ones are selected.
- The integration stage: the solutions are transformed into a particular invention.
- In the development stage, the prototypes are tested and evaluated by deciding whether the "innovation" is launched or not. Also, an evaluation of all the stages is carried out.

4.4.2 The Operational Level

The operation level is the core of the innovation process where an opportunity is transformed into a novel inventive product. This level encompasses four stages: (1) In the Define the problem stage, the opportunity is translated into the problematic situations which are analyzed. Then, using the network of problems, the problem from these problematic situations is formulated. (2) The Source knowledge stage is aimed at resolving the problem and is divided into two sub-stages: the typical solution technology and the contradiction technology. (3) The most prominent solutions are tested and transformed into a realizable product in the Transform knowledge stage. (4) In the New source of innovation stage, the product is in the production and launch phase, the intellectual property is exploited. Additionally, all the best practices and the knowledge created during the stages are capitalized.

4.4.3 The Support Level

The support level aims at easing access to the necessary resources to carry out the activities and stages in the other upper levels. At this level, the activities fall into two subgroups: knowledge management activities to acquire, create, develop, share, transfer, transform, and apply knowledge during the innovation process. Knowledge includes a collection of problems, ideas, explicit knowledge, TRIZ tools and techniques as well as an internal collaborative network. This subgroup is managed by a knowledge management system to enhance both the ability to learn and the problem-solving skills. The other subgroup covers supplementary support activities such as patent analysis, communication, sourcing external knowledge, training, and teaming up with outside collaborators. An example of support activity is the introductory training session for the outside specialist collaborators who may not be familiar with the use of the OTSM-TRIZ tools and techniques.

4.5 Innovation Process Workflow Approach (IPWA)

In this section, we describe the workflow of the networks and the activities that are bound together during the innovation process workflow approach (IPWA).

4.5.1 Initial Situation

As a first step towards the innovation process, it is necessary to carry out the pre-processing of gathering and analyzing relevant information to identify promising innovation opportunities. The activities of strategic management and idea management are used to stimulate this step. Once the opportunities are defined, the innovation process starts as an innovation project. Thus, the management activities (project management, business portfolio management, and human resource management), as well as the support activities (collaborative network, idea database, knowledge database, problem database) are launched to contribute to this initial step.

4.5.2 Definition of the Problematic Situation

At this stage, the initial situation is defined as a problematic situation in a broad sense using generic concepts, rather than specific technical terminology. This definition includes the objectives, the main function, the desired functions of the system, the required improvements, and/or the undesired effects and drawbacks which have to be eliminated. This information can be obtained using the support activities (the knowledge database, problem database, and TRIZ knowledge and tools), through the expression of requirements and needs or analyzing the ideality of the system. The concept of Ideality implies the improvement, intensification and/or acquisition of useful actions, and the elimination, prevention, or reduction of harmful actions (Terninko 1997). At the end of this phase, all the elements in the initial situation are translated into goals to be achieved and the barriers to overcome. The term barrier refers to problems, undesired effects, harmful actions, or constraints that limit the evolution of the system or process.

4.5.3 Network of Problems/Solutions

This phase covers two steps: first, we start to search and collect information related to the goals and barriers defined in the earlier phase. For example, we can search for the principal causes of a specific problem and workable solutions or how we can achieve a specific goal? This information can be obtained from the participants in the project, the knowledge database, problem database, idea database, TRIZ knowledge and tools, the patents, or the scientific bibliography. Then, the obtained information is analyzed to create different descriptions (or interpretations) of the problematic situation to create a network of problems.

In the second step, once that relevant information is extracted and analyzed from various sources to create a description of the problematic situation, it needs to be organized to represent some meaning. This meaningful information is created by using a graphical formalism called a network of problems (Khomenko et al. 2007). The building of this network involves translating the information into goals, problems (only some constraints, but not the complete set of them), and partial solutions, depending on the context. A partial solution is a solution that solves only one part of the problem or creates another problem. Then, the problems and solutions are presented as nodes and linked between them by arrows Khomenko and Guio (2007) to create a tree structure.

Finally, it is necessary to choose the most important problems to solve or the best solutions to implement. These principal problems and solutions are defined as "bottlenecks." According to Khomenko and De Guio (2007), a bottleneck is a node that has several inputs (incoming arrows) from different problems or solutions that are acting as a principal barrier in the evolution of the technical system. Therefore, by removing the bottlenecks all the problems linked to them can disappear.

4.5.4 Problem Definition

This phase consists in representing each bottleneck as a well-defined problem situation. Following the TRIZ theory, a well-defined problem is defined as a conflict between the actual situation and the desired 'ideal' situation that cannot be reached due to some barriers that must be eliminated (Khomenko and Cooke 2010). For example, we can describe a problem as the conflict between the solution to reach a desired state and the barrier (which prevents the solution to be implemented).

4.5.5 Problem Evaluation and Selection

One problem is classified as inventive if it is ill-defined or if there is a lack of information and knowledge to solve it. Thus, the purpose of this evaluation stage at the management level is to analyze the problem to classify it into one of the three predefined types:

- The problem is trivial, and it is not necessary to execute the innovation process. Trivial because it can be solved using a well-known method or the existing knowledge in the company. In TRIZ, these problems are defined as a solution with the first level of invention.
- The problem is ill-defined (problem unclear) and the process must be restarted (from the initial situation or redefined).
- Inventive because there is a lack of knowledge to solve it, and then it is necessary to "source the required knowledge" in the next step.

4.5.6 Typical Inventive Solution Technology

The typical inventive solution technology aims to solve the problem using different problem-solving tools and the existing solutions that have been developed and used successfully in the past to solve problems, these are:

4.5.6.1 Experience and Knowledge

This tool involves information about solutions based on the experience of participants (collaborative database and knowledge base), problems capitalized in the problem database, and/or solutions in the literature (manuals, patents, journals, etc.). All this information can be useful to provide the desired action to eliminate the problem and generate one (or several) solution(s).

4.5.6.2 The Scientific-Engineering Effects

The aim of this tool is to identify a chemical, biological, geometrical, physical phenomenon or effect that can suggest new alternative ideas or solutions to overcome the barrier. To make this possible, the desired action or the way to eliminate the harmful action defined in the problem is described as a specific effect/phenomenon or as a function that can be formulated as an action verb + noun (Sokol et al. 2008). Then, a knowledge base of effects is used to associate the effects of this specific function. Finally, the retained effects are interpreted and adapted to the specific situation to generate one (or several) solution(s). Examples of effect databases are the Production inspiration database (AULIVE n.d.), the HIS Goldfire Scientific Effects (Invention Machine n.d.), or the list of effects in the TRIZ literature (Salamatov 1999; Savransky 2000). Sometimes to implement the effect into a concrete solution, the resources could help to make the effect realizable. The way to identify, introduce, and use all the relevant resources is detailed in Negny et al. (2012). Thus, it is better to consider the existing resources of the system or process under analysis.

4.5.6.3 The Standard Solutions

The idea hidden behind the standard solutions is to create an abstract representation of any problem in a technological system as a set of substances, fields, and their interaction (Substance-Field System). Later, the “standards” propose solutions to deal with this problem. The standards are ready-made solutions that include rules (recommendations) that define the required type of modifications in the existing system to achieve the desired result (Salamatov 1999). The standard solutions are contained in the TRIZ knowledge base and toolbox.

4.5.7 Solution Evaluation and Selection

At the end of the typical solution technology, one or several solutions obtained are evaluated at the management level. If the solution (or solutions) can be considered relevant, the knowledge is transformed into a tangible invention. On the contrary, if a satisfactory solution cannot be found, we are facing a not typical inventive problem. Then, we need to use the contradiction technology to try to solve the current problem.

4.5.8 Contradiction Technology

When the typical solution technology does not provide a workable solution for overcoming the problematic situation, we are facing a non-typical problem with a hidden contradiction. Hence, we need to find and formalize this contradiction, and then try to solve it. By analyzing this contradiction, we can obtain a better understanding of the problematic situation and a way to propose and evaluate the solutions. The problem-solving process in the contradiction technology is subdivided into three steps:

4.5.8.1 Network of Parameters

The network of parameters is created through contradictory situations of non-typical problems. A contradictory situation arises when the attribute of a system (called control parameter) conflicts because its desired value has a positive and negative influence on other attributes (also called evaluation parameters) of the same system, in another system or its environment. The typical solution (from previous steps) defines the control parameter which has two or more alternatives or opposite values. The problems or advantages associated with this typical solution are the evaluation parameters influenced positively (desired) or negatively (non-desired) depending on the value of the control parameter. From this situation, we need to extract and represent the contradictions in the next step.

4.5.8.2 Network of Contradictions

This network represents each contradiction as the conflict between the human wishes (that express the most desired result) and the laws of physic in the form of barriers (that prevent the achievement of these wishes) (Khomenko et al. 2007).

A contradiction states the contradictory values of the control parameter to obtain the desired value of each evaluation parameter. Thus, it is necessary to define the most desired value of the control parameter, the most desired situation of evaluation parameters, the barrier, and how this barrier prevents us from reaching this desired result. The value selected in the control parameter can be the most proper value for the problematic situation or the value defined by the laws of physic. This value is associated with the improved evaluation parameter, while the barrier is associated with the degraded parameter. Finally, all the contradictions that have been found are integrated into a network of contradictions. The network of contradictions is the representation of the crucial problems (or contradictions) that prevent the evolution of the technological system under analysis.

4.5.8.3 Solving Contradictions

This step aims to transform the contradictions defined in the network of contradictions into a typical contradiction TRIZ model, and then try to solve these contradictions using different TRIZ tools. The choice of the tools depends on the specific information obtained during the creation of the networks. The TRIZ knowledge base and toolbox contain different tools used for solving the contradictions. These are described and detailed below.

The Scientific Effects

After analyzing the networks, if the desired action to solve the contradiction can be defined, then the scientific effects tool can be used. For example, a contradiction states that the object must be liquid to flow and solid to not flow. Then, using the scientific-knowledge base of effects, this desired action is defined as the function "change the physical state of the object," and the melting point has the effect that provides this function. More detail about this tool is described in the typical inventive solution technology.

The Technical Contradiction and the Contradiction Matrix

When it is not recognizable which action is necessary to solve the contradiction, another alternative is to transform the problem into a technical contradiction and use the contradiction matrix. The contradiction matrix is a TRIZ tool that maps the most promising inventive principles that were successfully used by other designers to eliminate technical contradictions. The tool expresses the conflict between two technical parameters in a system (Altshuller 1999). The process to eliminate the technical contradiction using this tool is as follows: we need to identify the parameters in the contradiction. Next, once the parameters in conflict are defined, they must be interpreted as one of 39 engineering parameters defined by TRIZ. Then, using the contradiction matrix, we need to select, in the column, the parameter that is improved and in the row the parameter that is worsened. The numbers in the intersecting cell correspond to the most suitable inventive principles to solve the problem. Also, these principles are ranked in the recommended order of use. Finally, during the analysis process and ideation, these principles are used to create different concept solutions to solve the contradiction. This matrix is therefore a vast feedback on past problems and their associated inventive solutions gathered in the patents.

The Physical Contradiction and the Separation Principles

If the problem requires that the control parameter must have two opposite values—one value to satisfy the desired state of one evaluation parameter and another opposite value to eliminate the barrier associated with the other evaluation parameter—, then we arze dealing with a physical contradiction that reveals the physical root cause of the problem. To solve this physical contradiction, we need first to formulate it using the networks of parameters and contradiction as follows:

The <Element> should <the value of the control parameter, e.g. be hot> in order to <describe the desired state or behavior of the improved evaluation parameter> , but it should <the opposite value of the control parameter, e.g. not be hot> in order to eliminate or prevent <describe the harmful behavior of the barrier associated with another evaluation parameter>.

Next, we define the type of conflict between the opposite values: the conflict occurs at separate times; the conflict occurs at different spaces; or the conflict occurs in the same space and time. With this last conflict, we have two options: separation under condition or separation between the entire system and its parts. Finally, we select from the eleven separation principles, the most relevant principle associated with each type of conflict. This principle guides us to generate the concept solution (Orloff 2006).

The Standard Solutions

This tool is used when it is possible to define the interaction or behavior among the existing substances and fields in the contradiction. The process to use this tool has already been described in the typical inventive solution technology. The difference here, however, is that the networks can help us to find the specific undesired or missing behavior, as well as the substance and fields, and their interaction in the core of the problem.

4.5.9 Design Adaptation

After having created one or more conceptual solutions using the typical solution technology and/or the contradiction technology, the next step is to adapt them into a conceptual design and develop different concept variants. Then, the solutions are defined as concepts with explicit details about the components and their spatial and structural relationships. Each concept includes diagrams and sketches to explain the working principles. In this preliminary design, the final specific parameter values and materials are not yet defined.

4.5.9.1 Concept Evaluation and Selection

The adapted concept solutions are subject to evaluation at management level. The purpose is to identify the most suitable concept to develop in the next stage. The criteria to evaluate the concepts are, for example, the specific conditions, constraints (goals, specifications, and requirements), and the possible obstacles that will arise during the implementation. Thus, after analyzing the advantages and disadvantages of the different design variants, the most promising design concept is selected to create a prototype.

4.5.9.2 Prototyping

Prototyping is an early working version as an attempt to embody the conceptual design into a tangible representation of the product before moving to mass production. This representation describes the purpose of the product with a precision of details of its form and parts, giving an early perception into how the product will do and look (Beaudouin-Lafon and Mackay 2020). Thus, in this stage the prototyping consists of the development the necessary components, and the definition of the materials, properties, form, dimension, and geometry of all individual parts as well as the cost estimated and the production planning process.

4.5.9.3 Product Evaluation

In this section, important decisions need to be taken to determine whether or not the prototype can be considered as an innovation that can be commercialized successfully. Thus, in this evaluation stage, one or more prototypes are manufactured and tested. In this test, it is necessary to consider the user interaction, the product life cycle, to analyze and compare the strengths and the weaknesses with existing products on the market, and that it meets the needs of its user. Thus, if this is a new form of innovation, that is technically and economically feasible to produce and commercialize, then, the next stage is triggered. In any other case, it is necessary to decide whether to finish the innovation process or to step backward in the innovation process.

4.5.9.4 Exploitation

This stage triggers different activities to introduce the product into the market and ends the innovation process of this product in the firm. These activities are:

- Production and commercialization. This activity includes the project planning, production, process instructions, assembly, testing, transport, distribution, application, and recycling.

- Intellectual property. This activity covers all the patents and designs of the product as a result of the innovation process.
- Knowledge capitalization and best practices. The knowledge and information during the innovation process are capitalized. The underlying goal of this effort is to collect all problems, failures, solutions, ideas, lessons learned, best practices, or scientific-engineering effects. This knowledge could be available and reused in a knowledge management system for the future innovation process. The aim is to reduce the effort associated with the reinvention of a new solution, in the same way as the case-based reasoning method (Cortes Robles et al. 2009).

4.6 Case Study

In recent years, the agenda of the food processing industry is to find a balance between economic growth and environmental sustainability. Thus, this industry seeks to facilitate this equilibrium by exploring opportunities to reduce the environmental impact. In this regard, a food production plant aims to improve its spray drying system as an environmental strategy.

Spray drying is an energy-intensive, but economically suitable technology consisting of the removal of liquid from solid solutions by evaporation, resulting in dried powder and hot moist gases. The powder is collected, and the moist gases are vented out (Patel and Bade 2019). Although this process is one of the most used drying technologies to produce high-value particles, it consumes a large amount of energy and has large energy losses. According to (Julklang and Golman 2015), the energy lost is around 29%. Another issue is that some dried particles are not retained and thus released into the atmosphere. Thus, with the rising interest in sustainability, the firm aims to start the innovation process to reduce wasted energy and reduce exhaust air pollution in the spray drying process. In this example, we focus our attention mainly on the problem-solving process, which is presented in detail.

4.6.1 Initial Situation

After analyzing the process at management level, one improvement opportunity was found in the temperature of the exhaust air that could reach 70 °C. This heat waste in exhaust gases offers significant potential available for recovering and then reducing heat losses. Another opportunity is to reduce the powder particles outgoing from the collectors and thus preventing a form of pollution.

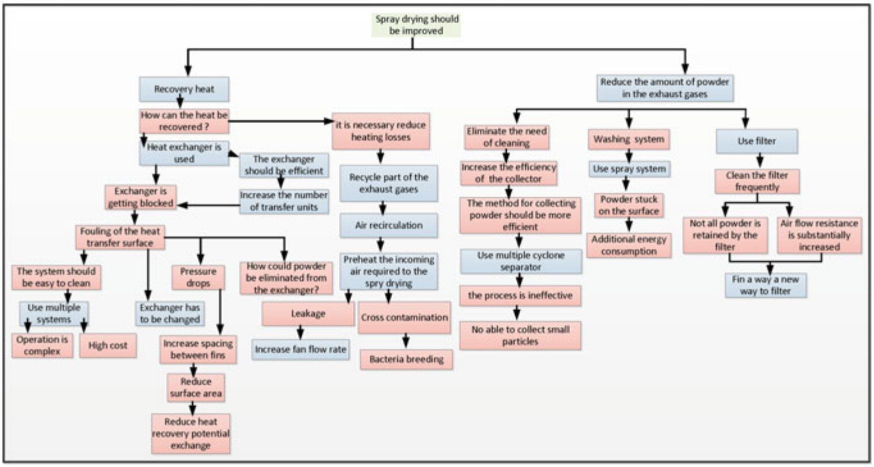


Fig. 4.3 Network of problem/solutions

4.6.2 *Problematic Situation*

The problematic situation in the spray drying system is to investigate alternative heat recovery methods, and a means for removing the amount of powder from exhaust gases. Thus, we need to find: (1) a way to reduce the amount of powder in the outlet gas stream or to make more efficient the method for collecting powder (2) a way to recover or reuse the heat losses in the outlet gas stream.

The network of problems/solutions is created by analyzing the two main problematic situations (Fig. 4.3). One part of the network shows the possible possibilities to recover heat losses. The solution for recycling a portion of the exchange gases is excluded. Thus, we prefer to use a heat exchanger. However, to apply this partial solution, it is necessary to eliminate the problem of fouling. This problem is related to the existence of powder in the exhausted gases. In the other part of the network, the problem of reducing the amount of powder in the exhaust gases could be solved using a filtration system. This solution is also followed by the problem of maintenance and complexity of the system. Also, the filtration system could interfere with the heat exchanger.

4.6.3 *Problem Definition and Evaluation*

The problem to improve the spray drying system analyzed consists of two bottlenecks:

- To have an efficient heat exchanger to recover heat losses that can prevent the accumulation of fouling or it can be cleaned by itself.

- To have a separation system to reduce the amount of powder in the exhaust gases that requires little maintenance, and it is able to retain small particles.

After evaluation, we go ahead to the next stage, but an additional requirement is suggested: the two systems cannot interfere with each other.

4.6.4 Typical Solution Technology

Considering the difficulty to retain small particles of the typical filtration system (e.g. bag filters), it is desirable to find new ways to separate. Thus, the scientific-engineering effects were used to generate a conceptual solution. The Goldfire Innovator database is useful to reach this goal. Different effects and phenomena were proposed: Applying an electrical field or ultrasonic field, using cavitation, and using mechanical purification using liquids.

For the second problem for the heat exchanger, the standard solutions were used. This tool proposes the standard solution *1-2-1*: the introduction of a third substance to reduce the harmful interaction between the exchanger and the exhaust gases that prevent the accumulation of fouling.

The solutions were evaluated. For the problem of filtering the solution considering the mechanical purification using liquids could be appropriate to implement into the process as it can be easily controllable. The other options were not considered for technical reasons. For example, the use of an electrical field could be complex and inefficient. For the problem of the heat exchanger, the use of lye to clean the exchanger could reduce its efficiency (the addition of a third substance). Thus, this last problem is considered non-typical and then, the contradiction technology will be used.

4.6.5 Contradiction Technology

The problem of the heat exchanger is transformed into a network of parameters that describes how the parameter values of the heat exchanger influence other parameters in the system. From this network of parameters, the most desired situation is selected to define the contradiction to solve (Fig. 4.4).

Then, we formulate the problem as a physical contradiction: a system should be present in order to recover the heat from the exhaust gases, but it should be not present in order to prevent fouling on the surface of the heat exchanger.

The only formulation of the physical contradiction guides us towards the idea that the existence of a heat exchanger suggests the presence of fouling. Conversely, the non-existence of heat exchange requires an alternative heat recovery system. Thus, using the "separation between the entire system and its parts" principle, "the system" should be in contact with the exhaust gases to exchange heat as a super-system and, as a subsystem under this condition, the exhaust gases do not get stuck

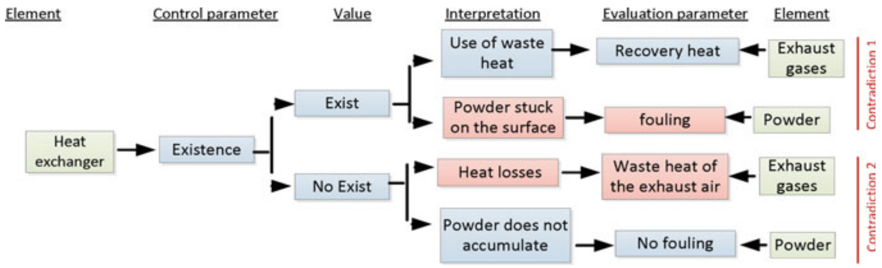


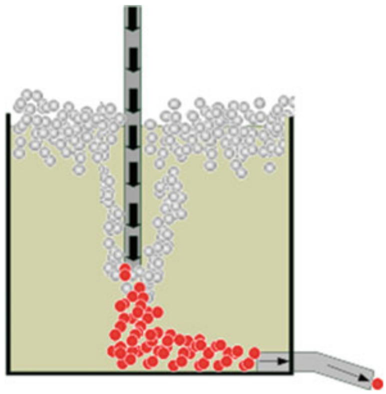
Fig. 4.4 Network of parameters and the contradictions

with the "system." A characteristic of "the mechanical purification using liquids" in the earlier solution is that the exhaust gases lose heat when passing through the liquid, in other words, the liquid exchanges heat or keeps heat. Thus, the system can be also used as a heat exchange without having the problem of fouling.

4.6.6 Concept Solution

The conceptual solution is a system for cleaning exhaust gases and storing heat using the principle of "the mechanical purification using liquids" (Fig. 4.5). Finally, during the concept evaluation, the solution of merging the two systems into a single system is an attractive solution for the managers.

Fig. 4.5 Graphic illustration of the mechanical purification using liquids



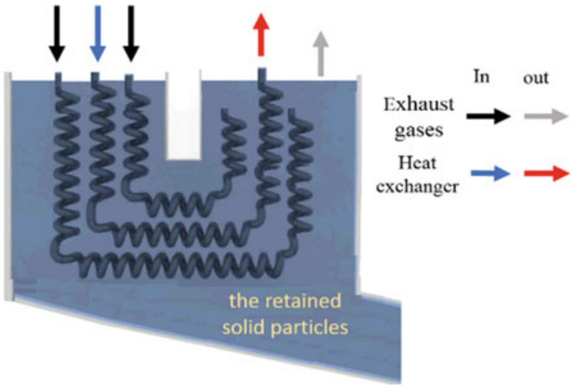


Fig. 4.6 The new heat recovery and cleaning system

4.6.7 Design Adaptation

Once the conceptual solutions were established, they are adapted to the characteristics of our problem. The process to transform a concept into a physical system is a complex process that requires knowledge from multiple disciplines. Thus, it was necessary to expand the number of collaborators and create team works for developing the conceptual design. An illustrative representation of the conceptual design of the new heat recovery and cleaning system for the spray drying process is shown in Fig. 4.6. The system works as follows: the exhaust gases flow through a tube immersed into the liquid. The gases bubble up from the tube, the liquid keeps the solids particles and the heat from the gases flows to the liquid. The heat can be reused for the hot gas stream or the slurry feed by a pipe in the container working as a heat exchanger. This system is installed near to the gas outlet. Finally, in the next step, the design concept is verified and tested with a prototype.

4.6.8 Exploitation

No matter what happens with the prototype (failure or innovation). In this stage, the relevant knowledge used and the lessons learned are capitalized in the knowledge management system. Examples of capitalized knowledge during the innovation process are:

- The recycling of the exchange gases can also have a negative effect (can contaminate).
- Explore the use of electrical field or ultrasonic field to clean gases.
- The mechanical purification using liquids has additional functions such as retaining or removing heat.

4.7 Conclusion

The Innovation process workflow approach presented in this chapter describes the required steps and activities of the knowledge transformation process during the innovation process. An innovation process that is not linear, but a multi-layer with ups and downs between levels, and feedback loops.

This approach is based on the OTSM-TRIZ method to support the problem-solving process during the innovation process in the food industry. Its strengths are based on the potential of the TRIZ theory to solve inventive problems through a set of concepts and tools. Such concepts and tools propose creative solving strategies that are based on extensive analysis of the evolution of technological systems, and natural science. To overcome the limitations of TRIZ theory, such as solving multidisciplinary problems, the analysis of the initial situation, and solving only one contradiction, the General Theory on Powerful Thinking (OTSM) is used. OTSM can offer a deeper understanding of the initial problematic situation to formulate and prioritize the crucial problems in an organized way and allows the formulation of several contradictions. The synergy of OTSM-TRIZ presented in this research provides a systematic procedure to solve typical and complex (inventive) problems. Also, the OTSM-TRIZ networks offer a way to capture, organize, and formalize the existing knowledge and information produced during the problem-solving process. This knowledge and information can be reused to generate technical solutions, prevent future failures, and evaluate the solutions proposed during the problem-solving process. Furthermore, the approach can also be used as a framework to guide the choice between the concepts and tools of the TRIZ theory to be implemented during the preliminary stages of the innovation process, which is a well-known issue for TRIZ practitioners (Ilevbare et al. 2013).

The case study in this research showed the applicability of the proposed approach in the improvement of spray drying technology. The result is the conceptual design of a new heat recovery and cleaning system as a sustainable solution. However, some limitations were found during the innovation process. For example, the search for specialists delayed the project. This was because the approach lacks a method for finding specialists that could take part in the current project. This limitation could be overcome with the collaborative mechanisms as used in collective intelligence (Flores et al. 2015a) or open innovation (Flores et al. 2015b). Another limitation was during the creation of the network of problems. The acquisition of information is a complicated and time-consuming process. This process could be reduced in difficulty by the integration of a semantic search engine.

Finally, the approach presented is the response to overcome the difficulties during the innovation process in the food industry that can play a crucial role to drive innovation in the “new economy”.

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Chapter 5
New Services Ideation: IDEATRIZ Methodology Application

Ana Paula Weigert and Marco Aurélio de Carvalho

Abstract IDEATRIZ methodology includes value analysis, systematic and heuristic methods coming from TRIZ methodology to generate product ideas in the manufacturing field. TRIZ has already its application extended to several areas of knowledge such as quality, energy, and services. Due to the current need for innovation in the service area, it was proved through this study that IDEATRIZ can be a powerful tool for generating service ideas. This paper presents an adaptation of the IDEATRIZ methodology for service ideation. The research begins by evaluating previous studies that propose methodologies using TRIZ for services, apply the original IDEATRIZ for service generation, adapt IDEATRIZ for services, and apply again for idea generation. As a result, it was confirmed that IDEATRIZ can be used for generating service ideas and there is a slight improvement in the quality of ideas by using the adapted IDEATRIZ compared to the original. The inclusion of examples of service ideas in the heuristics and inventive principles stage in the adapted IDEATRIZ that facilitated the use of the methodology by opening the field to the use of IDEATRIZ as a support tool and service innovation and creative problem solving for this area.

Keywords Fuzzy front-end · Service innovation · Ideation · TRIZ

5.1 Introduction

Markets are changing, facing rapid and drastic structural changes, and bringing speed to service development. This is possible due to the advancement of the use and massification of telecommunications, Internet-based virtual processes, internationalization, global strategic alliances, and the advancement of technology, generating a new economy. Innovation starts with an idea. The early stage of the innovation process is called the term 'front end' of innovation. Methodologies such as TRIZ can be used in the conception of new service concepts (Zhang et al. 2005). TRIZ methodology provides systematic thinking methods for problem identification, analytical tools for

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problem modeling, analysis, and transformation, knowledge-based tools for system change, and new product development solutions (CHOU 2014).

According to Sundbo and Gallouj (1998), service innovation can be the creation of new knowledge or information service, or new ways of dealing with artifacts or people, which are just new forms of service delivery that are usually minor service adjustments. processes, incrementally and rarely radically. Service innovation is the change of a business by adding a new element or a new combination of old elements.

Artifacts and services are being sold and consumed but are being offered as solutions, systems, or functions. But more generally, the service itself or the information provided is a major component of various artifacts. Thus, the boundaries between sectors are becoming blurred and the uncertainty of the precise nature of what is called 'product' is increasing. Service innovation can occur in many sectors in both manufacturing and agriculture (Gallouj and Djellal 2011, p. 19–20). Innovation is beyond the creation of products. It is increasingly related to the creation of services added to these products to improve business opportunities (Lee and AbuAli 2011; Lee et al. 2015).

For Gottfridsson and Stålhammar (2014) the idea generation process is present in all service innovations and should include a combination of actors with different types of knowledge and have a space for cooperation and interaction between them. Although interest is increasing in the front-end stage of innovation, there is restricted literature on ideation related to product and service development (Kock et al. 2015).

According to Drejeris and Tunčikienė (2010), the company should choose the best ideation method for its need and does not indicate especially a method designed for service ideation. But researchers like Kim and Park (2012) and Gazem and Rahman (2013) propose specific methods for ideation services by exploring the 40 inventive principles of TRIZ, which is Altschuller's (TRIZ leading creator) most popular tool. Altschuller has analyzed inventions documented in patents and other technical documents to find a kind of pattern of the invention and establish steps and recommendations to be followed to exclude the psychological approach to have creative ideas (Li et al. 2007).

A typical TRIZ-based problem-solving process is comprised of 3 stages: problem definition, problem-solving, and solution evaluation (Chae et al. 2012).

Gazem and Rahman (2013) approach service redesign from features most commonly found in service operation, and Kim and Park (2012) propose a method for service generation to support product design. By comparing the methods against the typical stages of troubleshooting using the TRIZ, both methods have limitations on exploring the use of TRIZ tools.

In the problem definition stage, the method by Kim and Park (2012) uses the ISQ (Innovation Situation Questionnaire), but the method by Gazem and Rahman (2013) does not explore this stage, which could use tools such as ISQ, Ideal Final Result, and Function Analysis. In the problem-solving stage, both methods present approaches that facilitate the understanding of the use of TRIZ, relating the inventive principles to important decision-making factors for service acquisition and typical solutions to problems commonly encountered in services.

Kim and Park's (2012) method explores TRIZ's tools and the assessment of contradictions, which are the TRIZ's base pillars in more elaborate ways. The advantage of the method by Kim and Park (2012) is that it can be applied to integrated product-service systems, allowing for broader use of the method. The method by Gazem and Rahman (2013) is indicated for service solutions that involve typical operations bringing a step-by-step guide to the creation of service solutions. Its advantage is that it predefines solutions that could be better explored to compose the typical stages of TRIZ problem-solving.

The study aims to prove that due to the few applications of using TRIZ for service ideation, the IDEATRIZ methodology, created by de Carvalho (2011) can be used to generate service ideas, and explores the 3 typical stages of TRIZ troubleshooting: problem definition, problem-solving, and solution evaluation.

5.2 Research Method

To explore the application of the IDEATRIZ methodology for services and to evaluate the quality of the generated ideas, action research was conducted. Regarding the validation of the hypothesis, quantitative research will be adopted, as statistical data will be used to analyze and compare the quality of the ideas generated by the original and adapted methodology. Besides the limitation of non-statistical use, they will not be generated and compared with ideas generated by other methods such as Gazem and Rahman (2013) and Kim and Park (2012) addressed in this article.

In action research initially is assigned to a practical problem, then solutions are sought to achieve a possible transformation within that observed situation or a goal to be achieved. To formulate the problem, initial analysis and delimitation of the initial situation are performed, the final situation is demarcated, identification of the problems to be solved to move from an initial to the final solution, planning the corresponding actions, their execution, and finally the implementation and assessment of action results (Thiollent 2011, p. 62).

The hypothesis raised is that the IDEATRIZ methodology (de Carvalho 2011) can be directly applied to the ideation of services but will generate lower quality ideas compared to the same methodology adapted for services.

Based on the authors Amabile (1996, p. 34–37) and Schuhmacher and Kuester (2012), the quality of ideas can be measured by the criteria: novelty, viability, and relevance. These criteria were used to evaluate the ideas generated by the original and adapted IDEATRIZ methodologies. The variable "Novelty" refers to how unique the product is, the "Viability" variable refers to how much it is possible to implement a certain idea given the available resources available and the "Relevance" variable how important this idea is to the business, either from the service user or the service provider. The analysis of these ideas was performed according to the consensual analysis proposed by Amabile (1996, p. 42–44) where 2 independent experts in the area in which ideas are being generated should evaluate them. The score used for each criterion was given on a Likert scale from 1 to 7, with the lowest score being 1 relative to the criterion and the highest score 7, that is, which best meets the criterion. The maximum score an idea's quality can achieve is 21.

To validate the hypothesis, it was necessary to apply it directly to the ideation of services, to identify the problems found in its use, and then to adapt it, reapply it and compare the quality of the ideas generated. The author evaluated the indicators regarding the "Degree of difficulty of understanding methodology" and "Degree of difficulty to find analogies for services", the suggestions and difficulties raised in the first applications of the use of the original IDEATRIZ to create the adapted IDEATRIZ.

The research discussed in this article can be divided into five main sections:

1. Application of the original IDEATRIZ methodology (de Carvalho 2011) to generate service ideas and evaluate their use;
2. Analysis of the application of the original IDEATRIZ;
3. IDEATRIZ methodology adapted for service ideation;
4. Application of IDEATRIZ methodology adapted for services;
5. Analysis of the application of the adapted IDEATRIZ.

The author held 6 workshops where practices were used to generate ideas to improve an Online Consulting service. In these workshops were collected the service ideas through the original and adapted IDEATRIZ methodology. Of these 6 workshops, 3 were applied for ideation using the original methodology and 3 were using the adapted methodology. To compare the results, the workshop participants' profiles, workload, and the same experts were maintained to analyze the ideas generated using the original and adapted IDEATRIZ.

The workshops were held at HOTMILK, startup accelerator at the Pontificial Catholic University of Parana (PUC-PR), the Technological University of Parana (UTFPR), and the Brazil Educational Program for iOS Development (BEPiD), a training program of iOS application developers—sponsored by Apple and partnered with PUC-PR.

In the HOTMILK workshops entrepreneurs, startup entrepreneurs, and students of computer or software engineering participated. In the workshops held at UTFPR were public servants of the University and students who perform fellowship activities within the University. The BEPiD workshops were attended by professionals with market experience and students mainly from the technical area of software development, automation, and games. At the end of each workshop, participants were invited to evaluate the methodology.

In the choice of evaluators, priority was given to professionals with experience in the area of Online Consulting, who were users of these sites and/or worked with online services. The involvement of specialists in this market has been based on the analysis of ideas. The E1-referenced expert has 10 years of experience in services, engineering, and consulting, and the E2-referenced expert has 6 years of experience in product design creation, innovation, design, and consulting.

5.2.1 Application of the Original IDEATRIZ Methodology

IDEATRIZ encompasses TRIZ's systematic and heuristic methods for designing manufacturing-oriented products, based on heuristics and value analysis that can be re-evaluated for use within the service innovation literature.

IDEATRIZ was built on techniques and approaches for ideation of new products based on value concept pillars referring to customer needs and product voice strategy, concepts of incremental innovation, and finally TRIZ theory and its derivative GTI (General Theory of Innovation).

IDEATRIZ is structured in 4 steps: 1st—definition of the product to be heard, 2nd—Use of the heuristics tree for ideation; 3rd—Formulation and resolution of contradictions; and 4th—Evaluation of the solution with voting and multicriteria analysis. The steps are presented in Fig. 5.1.

In the first step, *the Definition of the product to be heard*, the decision is based on the multicriteria analysis of which product within the company's portfolio or in other markets that may be explored by the company that represents the highest customer value and have the greatest potential profit.

In the second step, *Applying heuristics to increase value*, it used a tree created by de Carvalho (2011, p. 157) formed with TRIZ-based heuristics. Figure 5.2 is a clipping of the heuristics tree:

This tree was built to guide the generation of ideas to increase the value. The value is directly proportional to the functions and inversely proportional to the cost, represented by the formula $V = F/C$, where V means Value; F represents the functions or features that the product provides, and C represents the connections that are required to provide the functions. The value increase is achieved by changing the function and connection variables in the following scenarios: maintaining functions and reducing connections; increasing functions and maintaining connections; increasing functions and connections while maintaining value ratio; increasing functions and reducing connections; reducing functions and reducing connections while maintaining the value ratio. After this step, some ideas are already generated.

In the third stage, *Formulation and Resolution of Contradictions*, the technical or physical contradictions of the ideas generated by the tree are constructed. Technical

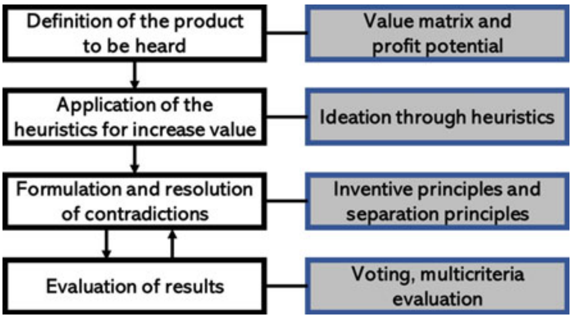

Fig. 5.1 IDEATRIZ methodology phases and tools (de Carvalho 2011)

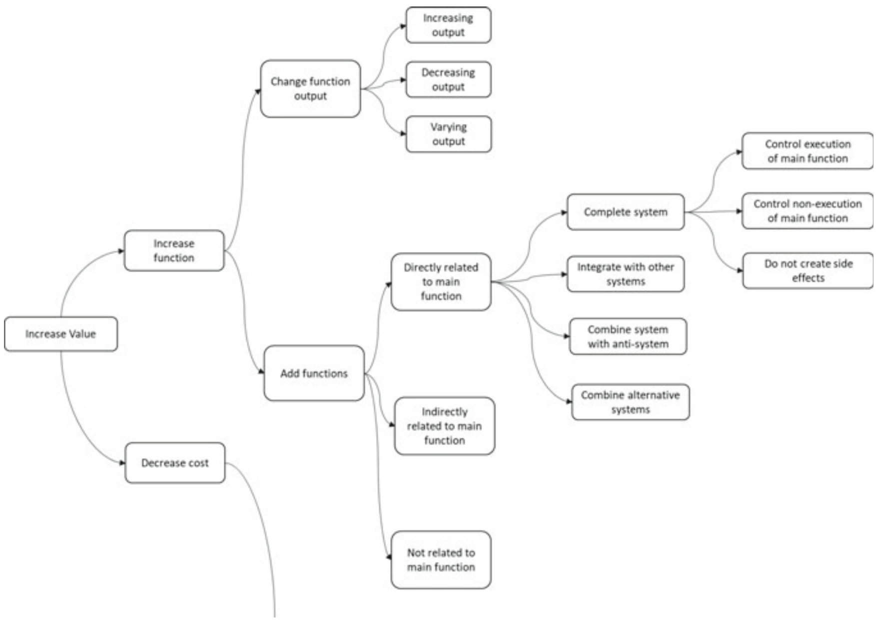

Fig. 5.2 A cutout of IDEATRIZ heuristics tree (de Carvalho 2011)

contradictions or pairs are those where there are conflicts in different parameters in the same system. For example Weight x power of a car. Physical contradictions are those where there are conflicting values for the same parameter. For example, tire rubber needs to be harder for durability and softer for grip. When a feature is improved, another feature may consequently be made worse. At this stage, the technical or physical contradictions of the ideas generated by the tree must be formulated and resolved. The resolution of contradictions brings more ideas to the product.

After identifying the contradictory technical characteristics for a generated idea, conversion of these for the engineering parameters should be made. Technical contradictions or pairs can be resolved through the "Inventive Principles Method" and physical contradictions through the "Separation Method". The Inventive Principles Method (MPI) is the most popular method of TRIZ that is mistaken for the whole TRIZ. The MPI elements are (a) engineering parameters; (b) matrix of contradictions; (c) inventive principles.

In formulating the technical contradiction, after raising the conflicts in different parameters for a given system, they must be translated into Altschuller's 39 engineering parameters (de Carvalho 2011, p. 205–208).

Next, the Altschuller Inventory Principles Matrix (de Carvalho 2011, p. 229–232) should be used to refer to the Inventive Principle to be used to resolve such contradiction and generate the ideal solution. The Inventory Principle number indicated is obtained by crossing the engineering parameter to be improved with the engineering parameter to be made worse. A description of Alschuller's inventive principle with examples of product idea generation is available in de Carvalho (2011, p. 193–204).

If contradictory physical characteristics are identified for the generated idea, the method to be used is that of Separation. According to Altschuller et al. (1999), it is necessary to have a separation in space, time, system, or according to specific conditions so that the physical contradiction can be resolved. The contradiction must be considered to occur within a given system with certain operating times, parts, or specific zones of the product and tool. The contradiction must be formulated, and the contradiction must be solved based on questions raised by de Carvalho (2011, p. 168).

In the fourth step, *Results Evaluation*, the ideas with the greatest potential for implementation are evaluated and selected. In the evaluation of results, they evaluated and selected the ideas of important potential for implementation. The evaluation process should be carried out by one of 5 people, preferably from the top management of the company. The process begins with a presentation of the ideas and proceeds to the selection. If the number of ideas for a number less than or equal to 15 can be used in multicriteria evaluation directly. The evaluation of the ideas in the original IDEATRIZ was carried out through 5 levels of judging by judicious, being very bad (1), bad (2), medium (3), good (4), and very good (5).

For this study, an application of the original IDEATRIZ methodology was held with workshops that began with the introduction to the concepts of innovation and TRIZ followed by a description of the IDEATRIZ methodology steps including examples of product ideas generation using the heuristics and from the formulation and resolution of technical contradictions.

To begin the practice of idea generation the scope was closed, not evaluating the value and profit potential matrix. In the first stage of the methodology: Definition of the "Product to be heard", the generation of ideas within the "Online Consulting" service line was defined for the practice. The main feature of this type of service is to perform the activity or work remotely, having the Internet as the main communication channel, where financial management, business, business, legal, accounting, engineering, communication, creation, and design are observed. The Online Consulting services websites on the market such as workana.com, 99freelas.com.br, freelancer.com, upwork.com, and www.wengo.pt were presented to illustrate the scope to which ideas should be generated.

The effective application of the method began from the second stage, when the participants used the heuristic tree generated by de Carvalho (2011, p. 157) whose cutout is presented in Fig. 5.2, for generating service ideas. At this stage, the participants gathered in groups of 2–4 people and through the examples of idea generation using heuristics presented during the product ideation workshop. Ideas were generated by the groups to improve Online Consulting services.

The ideas generated using the heuristics tree were reported by the participants in a specific form, which is detailed in Fig. 5.3. In this form, the ideas generated, their description, and the heuristics that helped in the generation of that idea were noted.

Fig. 5.3 The cutout of the form for heuristic ideas (Author 2016)

Idea	
Description	
Related Heuristic	

In the 3rd stage, from the list of ideas generated by the heuristics in the 2nd stage, the participants formulated the technical contradictions from the identification of the improved characteristic and the worse characteristic for each idea.

Figure 5.4 shows the base example presented to participants during the workshop to formulate contradictions, translate into engineering principles and resolve contradictions with the Inventive Principles Matrix. The example relates to improving a container for storing a carbonated liquid that has a high stacking capacity for storage (de Carvalho 2011).

Then the participants translated into engineering parameters. Using the matrix of contradictions the inventive principles indicated to generate the best idea to solve the problem and improve the use of Online Consulting were found. At this stage, the participants used the following tables: 39 engineering principles by de Carvalho (2011, p. 205–208), Contradictions Matrix by de Carvalho (2011, p. 229–232), and 40 Inventive Principles with examples related to de Carvalho (2011, p. 193–204).

FORMULATION OF TECHNICAL CONTRADICTION	**CONTRADICTION IN ENGINEERING PARAMETERS**	**INVENTIVE PRINCIPLES INDICATED BY THE MATRIX OF CONTRADICTIONS**
Improved characteristic (IC) x Worsened characteristic (WC) Cost x Resistance if reducing packaging material reduces resistance for stackability	IC: Length of Stationary Object (4) x WC: Tension or Pressure (11)	#1 Segmentation or fragmentation #14 Recurvation #35 Change of parameters or properties

INVENTIVE PRINCIPLE (IP)	**GENERATED IDEA**
#1	Corrugated tin
#14	Bent shape allows pressure to contribute to increased mechanical resistance
#35	Heat treatment of material to provide more resistance

Fig. 5.4 Example of formulation and resolution of contradictions using the contradiction matrix. Adapted from de Carvalho (2011)

The 4th stage of IDEATRIZ refers to the evaluation of ideas and multi-criteria analysis that was not carried out during the workshop, but afterward. At the end of the workshops, participants were invited to evaluate the method. The assessment was collected by completing a specific form to obtain data on the "Degree of difficulty in understanding methodology" and "Degree of difficulty in finding analogies for services" scaled to 4 levels, identified from 0 to 3, with the level 0: found no difficulty, level 1: found little difficulty, level 2 found medium or normal difficulty, and 3 found very or high degree of difficulty. Concerning the "Degree of interest for innovation" the levels were arranged from 0 to 3, with 0: not arousing interest, 1: arousing little interest in innovation through the workshop, 2: arousing medium or normal interest, 3: aroused a lot of high interest in innovation.

5.2.2 Analysis of the Application of the Original IDEATRIZ

The results for analysis were obtained after application of the original IDEATRIZ in 3 workshops where 34 forms were filled out by the participants and 10 suggestions for improvement were collected.

After tabulating the results, regarding the criterion "Degree of difficulty of understanding methodology" it was found that 47% of participants indicated a medium or high degree of difficulty, 38.3% pointed low degree of difficulty and only 14.7% did not encounter difficulty. Regarding the criterion "Degree of difficulty in finding analogies for services", most participants, accounting for 82.3%, pointed out that they found medium or high difficulty in making analogies to the generation of service ideas through the method, and 11.8% had low difficulty and only 5.9% indicated that they had no difficulty. The methodology stimulated normal or high interest in Innovation in 67.7% of participants.

Most of the suggestions raised, totaling 70% of 10 suggestions, were to include analogies for services in both the heuristic examples and the inventive principles proposed by the IDEATRIZ methodology. Suggestions were then made for software automation of the methodology (10%), further examples of the application of the method (10%), and increasing the level of detail of the presentation of online consulting sites to then start the process of idea generation (10%).

After compilation, as a result of the participant's evaluation of the use of the original IDEATRIZ, it is highlighted that:

(a) Almost half of the participants (47%) had medium or high difficulty understanding the methodology and only 14.7% of participants had no difficulty;
(b) 82.4% had medium or high difficulty finding Analogies for services, and only 17.7% had no or low "Degree of Difficulty";
(c) 80% of the difficulties encountered relate to the translation of engineering-related product terms into the service area.
(d) 70% of suggestions for improvement cite the inclusion of service examples in heuristics and inventive principles.

The analysis of the result of the direct application of the IDEATRIZ methodology was used as a basis to adapt the methodology for services. These indicators were also used for comparing results between the application of the original and adapted IDEATRIZ methodology which will be detailed later in this article.

5.2.3 IDEATRIZ Methodology Adapted for Service

In IDEATRIZ, created by de Carvalho (2011), the resolution of contradictions is accomplished by using the Inventive Principles Method and also by using the Separation Method. IDEATRIZ's adapted proposal for services only explored the use of the separation method in the resolution of contradictions, including study proposals already made by Mann (2004), which uses the separation principles for the resolution of contradictions in Business and Management. Mann (2004) adapted the resolution of contradictions of the same parameter using inventive principles to solve contradictions between different parameters.

The adapted IDEATRIZ included examples of heuristics and inventive principles for services and maintained only the use of the separation principle method for resolving contradictions for the same parameter. The proposed use of separation principles for contradiction resolution was based on the study by Mann (2004, p. 291). The adapted IDEATRIZ was maintained with 4 steps as the original.

In the first stage of IDEATRIZ: *Definition of the product to be heard*, which includes the multicriteria evaluation to choose the product to which the methodology will be applied, it was proposed that IDEATRIZ adapted the inclusion of the rereading of some criteria related to products and directed also the context pertinent to the service sector, as regards intangibility, inseparability, variability, and perishability (Kotler and Keller 2012, p. 384–387). The criterion of "Ease of use" should also consider the experience resulting from the use of the service where there is the involvement of all variables relevant to the service that makes it intangible, such as the environment, service, and a product added to this service. In the "Durability" criterion one should consider inseparability, that is the ability to produce and supply simultaneously. In the "Ease of stock" criterion, it should be considered that the service itself cannot be stored, except in a product-service context, where an artifact is involved in providing the service.

In the second stage of IDEATRIZ, for the adapted methodology were included as examples of services compiled by the author as a reference to the use of the heuristics tree created by de Carvalho (2011) to generate service ideas. A clipping for heuristics is presented in Figs. 5.5 and 5.6. Figure 5.5 shows changing output examples for services.

Figure 5.6 shows heuristics examples for adding functions—directly related to the main function.

In the third stage of IDEATRIZ, for the adapted methodology, the resolution of contradictions is performed through the method of separation principles in line with Mann's proposal (2004).

Heuristics		***Example***
Increasing output	Delivering more with the same available feature	Delivering more services in less manpower through processes and tools to improve productivity. E.g. Pre-preparation of portions in restaurants. McDonald's Scoop for McFlurry.
Decreasing output	Delivering the minimum required for that type of service	Laundromat service. Online store offering only reduced colors of bedding. https://casper.com/
Varying output	Delivering the service or function differently	Providing the same service at busy times. E.g. Offering more shifts of children's parties on weekends. Cheaper air tickets at off-peak hours.

Fig. 5.5 Heuristic examples for changing the output (Author 2016)

The important thing in using separation principles is to assemble the problem description by raising which feature, for example, should be high but at the same time low, present but absent, large but small. This method analyzes a situation within a system where the same parameter has contradictory functionalities. These contradictory characteristics will be identified as A and −A, with A being the opposite of −A.

Considering an example of a maintenance department that seeks to solve a problem to reduce downtime and defects. In line with the technical tradition (method of inventive principles matrix), we seek to resolve the conflict between 2 different parameters: reducing downtime and defects increases job losses, i.e. DEFECTS X LOSS OF JOBS. In the line of physical contradiction (method of separation use), the conflict to be resolved must be within the same parameter MAINTENANCE DEPARTMENT: it is to want the existence of maintenance department “A” and not to want the existence of maintenance department “−A”. It is wanting the existence of the department so that there is no job loss, but not wanting the existence of the department because you do not want downtime and defects (Mann 2004). Strategies for eliminating contradictions include:

1. Separation in space;
2. Separation in time;
3. Separation under condition; and
4. Transition separation to an alternative system.

These strategies should be used in sequence from 1 to 4 hierarchically, where the first strategies 1, 2, and 3 are associated with a couple of questions: where, when and if, respectively. The author formulated a frame presented in Fig. 5.7 to guide the generation of ideas, which is based on de Carvalho’s (2011) guidance on the use of the separation principles and the generation of ideas from the resolution of an A and −A contradiction using the Separation Principles related to Mann’s Inventive Principles (2004).

Heuristics		***Example***
Complete system	Control execution of the main function	All-inclusive hotel services control all services provided.
	Control non-execution of the main function	Airfare services include hotel and travel insurance. E.g. LATAM trips.
	Do not create side effects	The hospital monitors the patient who has left the hospital via teleconferencing consultations reducing and controlling readmission to hospital laws. Generate ticket upgrade for executive class if overbooked on flights.
Integrate with other systems	Add other systems to add value to the service and facilitate the provision of the service offered.	Car parking offers washing services. Car insurance offers a car during repair time (service provided by a partner). Alternative payment services such as Paypal, Pagseguro, and MOIP (credit card gateways) are used on e-commerce sites that do not have their payment systems.
Combine the system with anti-system	Use unwanted factors for useful results	Solar energy is connected to the electricity grid (smart grids). Excess power generation is sent to the grid and is credited to the energy bill.
Combine alternative systems	Include other services linked to the main function	Cloud storage service comes as an alternative to computer hard drives. Fixed broadband access with alternative mobile broadband internet connection.

Fig. 5.6 Heuristic examples for adding functions—directly related to the main function (Author 2016)

To reduce the main difficulty of using the methodology relating to the correlation and/or translation of product (mechanical) terms to services, the author has compiled examples of services for the Inventive Principles to address the main suggested improvement by workshop participants. A clipping of these examples compiled by the author is available in Fig. 5.8 and was based on material from Mann (2004, p. 269–286), Zhang et al. (2003), and commercial services.

SEPARATION PRINCIPLE USED	QUESTIONS	IF THE ANSWER IS: YES	IF THE ANSWER IS: NO
1. IN SPACE	Do A and -A characteristics need to be present everywhere? Where I want A is the same place I want -A?	Try SP in time	Try the following Inventive Principles: #1 Segmentation #2 Extraction (Taking out) #3 Local quality #17 Transition into a new dimension #13 Inversion (the other way around) #14 Spheroidality (Curvature) #7 Nesting #30 Flexible films or thin membranes #4 Assimetry (Symmetry change) #24 Mediation (Intermediary) #26 Copying
2. IN TIME	Do A and -A characteristics need to be present at all times? When I want A is the same moment I want -A?	Try SP transition as per condition	Try the following Inventive Principles: #15 Dynamicity #10 Prior action #19 Periodic action #11 Prior protection #16 Partial or excessive action #21 Rushing through (Skipping) #26 Copying #18 Vibration (Resonance) #37 Expansion and contraction #34 Rejection and regenerated parts #9 Prior compensation #20 Continuity of useful actions
3. AS CONDITION	Do A and -A characteristics required to be present under all conditions? When I want A is the same condition I want -A?	Try SP transition to alternate systems	Try the following Inventive Principles: #35 Transformation of properties #26 Copying #1 Segmentation #32 Color changes #36 Phase transition #2 Extraction (Taking out) #31 Porous materials #38 Accelerated oxidation #39 Inert environment #28 Replacement of interaction system #29 Fluidity
4. TRANSITION TO ALTERNATIVE SYSTEMS 4.1 TRANSITION TO ALTERNATIVE SUBSYSTEMS 4.2 TRANSITION TO SUPERSYSTEM 4.3 TRANSITION TO ALTERNATIVE SYSTEM 4.4 TRANSITION TO INVERSE SYSTEM	Do A and -A characteristics need to be present at all times? When I want A is the same place I want -A?	Restart the attempt starting with the Space Separation Principle	Try the following Inventive Principles: #1 Segmentation #25 Self-service #40 Composite structures #33 Homogenety (Uniformity) #12 Equipotenciality #5 Consolidation (Combining) #6 Universality (Multi funcionality) #23 Feedback #22 Convert harm into benefit #27 Dispose #13 Inversion (the other way around) #8 Counterweight (Anti-weight)

Fig. 5.7 Frame for using the principles of separation with inventive principles (Author 2016)

	Inventive principle	Sub-principle	Examples
1	Segmentation	a. Split a system or object into independent parts. b. Make a system or object easily detachable. c.Increase the degree of segmentation	Create service packages. Format self-supporting franchises. Divide the company into different service centers. Segment the customer base according to their need, age, purchasing behavior. Hire temporary staff for short-term activities. Improve deliverables by segmenting service ranges into multiple categories. Pre-bundle services in telephone answering through an IVR. Use modular or virtual offices. Add customization to a basic service.
2	Removal or extraction	a. The. Remove or separate unwanted or unnecessary parts or property from an object or system. b. Extract only the desired part or property.	Use a system that learns user preferences and filters out non-useful information. Use semantic processors to extract knowledge from text. Home care. Provision of itinerant services through the use of mobile vans.
3	Localized Quality	a. Change a system, object, or external environment - from homogeneous to heterogeneous b. Assign different roles to each part of a system or object. c. Position each part of a system or object in the best operating condition	Offering distinct services for the disabled and the elderly. E.g. Assemble the layout to provide services to maximize sales and convenience. Self-service restaurants. The customer sets up his menu. E.g. Spedini - customer chooses pasta and sauces preferably during production.

Fig. 5.8 Examples of the inventive principle segmentation for services (Author 2016)

In the fourth stage of the adapted IDEATRIZ, it is proposed to use multi-criteria analysis that refers to the quality of the ideas generated regarding novelty, feasibility, and relevance through the consensus analysis proposed by Amabile (1996).

5.2.4 Application of IDEATRIZ Adapted for Services

The application of the adapted IDEATRIZ methodology was also carried out in workshops that began with an introduction to the concepts of innovation and TRIZ following the description of the steps of the adapted IDEATRIZ methodology.

The voice of the customer is a key variable to bring the need of the market to the development of services. In IDEATRIZ methodology, the voice of the client can be obtained within the practice of generating ideas by inserting the participation of various sectors of the company that has direct interaction with the client, such as the customer service area, and bring the participation of invited clients to the ideation workshops. During the practice, participants had the role of clients of the site, as freelancers looking for work, as the contractor or entrepreneur seeking professionals to perform tasks or projects on demand, thus bringing the voice of the client in the generation of ideas because some participants already had used this kind of service. The application of the adapted method also began from the second stage with the use of the de Carvalho heuristics tree (2011, p. 157) whose clipping is shown in Fig. 5.2. However, in the adapted methodology the groups had access to examples of heuristics for services as presented in Figs. 5.5 and 5.6 but for all heuristics trees.

In the adapted IDEATRIZ in the third stage, contradictions were formulated for the same parameter A and $-$A for the ideas generated by the heuristics in the second stage. With the guidance of the frame presented in Fig. 5.7, the contradictions were formulated and resolved, and participants had access to the examples of inventive principles for services whose outline is presented in Fig. 5.8.

Before exemplifying the use of the adapted IDEATRIZ methodology, by way of comparison, we return to an example of generating ideas for Online Consulting by the original IDEATRIZ method.

During the 2nd stage "Applying heuristics for value increase", in IDEATRIZ's original method, one of the ideas generated by one of the groups in the workshop was the inclusion of "Online Chat" on the website, and in the Formulation and Resolution stage of contradictions (3rd stage), the group formulated the following contradiction: "Convenience of use x Loss of information" which, using the "Inventive principles matrix", suggests the use of the following inventive principles # 4—Symmetry change, # 10—Preliminary action, # 27—Disposable objects and # 22—Turning loss into profit to solve it. The participating group used Inventive Principle # 10—Prior action to generate the idea of creating a communication channel for questions via e-mail, i.e. offline, to identify the customer and not lose track record of information. It also used inventive principle # 22—Turning loss into profit to generate the idea of building a knowledge base to be offered to other customers as an additional service package.

Compared to the use of the adapted IDEATRIZ method, the generation of the ideas in the 2nd stage occurs, in the same way, as using heuristics for tree-oriented value increase, however, counting on examples of services compiled by the author as shown in Figs. 5.5 and 5.6.

In the 3rd stage "Formulation and resolution of contradictions for the generation of ideas" the separation principles are used, where the contradiction is given by the same parameter: "I want online chat (A) $\times$ I don't want online chat ($-$A)". I want A for speed of service and I want $-$A because of the cost of 24 h human resource availability.

To exemplify the step-by-step of this stage using the framework presented in Fig. 5.7 (guiding the use of the principles of separation-related to the principles inventive yourselves for formulating and resolving contradictions for the generation of ideas) the following questions began:

1. Where I want "online chat" is the same place where I don't "want online chat"? Do the "online chat" and not "online chat" features need to be present everywhere? The answer to be given is "Yes, they should be on the Consultancy website". Then one must proceed to the use of the principle of separation in time.
2. Must the features of "online chat" and not "online chat" be present all the time? When I want online chat is it at the same time when I want no online chat? The answer to be given is "No, I don't need online chat all the time." Then one must proceed to the generation of ideas for resolving the contradiction using the inventive principles indicated for the resolution of the Inventive Principle in time. In Fig. 5.7 the inventive principles indicated for resolving the time separation principle are # 15—Dynamicity, # 10—Prior action, # 19—Periodic action, # 11—Prior protection, # 16—Partial action or excessive, # 21—Rushing through (Skipping), # 26—Copying, # 18—Vibration (Resonance), # 37—Relative change, # 34—Rejection and regenerated parts, # 9—Prior Compensation, and # 20—Continuity of useful actions. With this guidance and based on examples of services for the inventive principles whose clipping is available in Fig. 5.8, follow the ideas generated in this 3rd step:

   - PI 15: Dynamicity: Maintain an automated chat that algorithmically identifies word scripts with the most common questions and automatically shows wizard-like answers;
   - PI 10: Prior action: Maintain a FAQ (Frequently Asked Questions and Answers) for common knowledge area consulting issues;
   - PI 19: Periodic action: Provide online chat opening hours that professionals will be available to answer questions and advise;
   - PI 11: Prior Protection: When chat is offline, provide the option of sending email to consultants.
   - PI 16: Partial or excessive Action: Show online and offline chat times.
   - PI 21: Rushing through (Skipping): Use of FAQs (Frequently asked questions) or wizard method to quickly guide the steps to be taken by the customer within that area;
   - PI 26: Copying: Use of automated scripts based on questions already asked and answered previously (use of knowledge base);
   - PI 18: Vibration: Increase the availability of online chat only for the knowledge area that has the most demand on the site; the other areas use longer offline chat time;

- PI 37: Relative change: Use consultants from other countries, with different time zones, to answer the online chat;
- PI 34: Rejection and regenerated parts: (no idea found to use this principle within this example);
- PI 9: Prior compensation: Providing an FAQ with common questions and answers on the consulting site;
- PI 20: Continuity of useful actions: Create shifts with consultants from other countries to cover missed hours in Brazil's business time zone.

Using the original IDEATRIZ, ideas were generated to create a communication channel for questions via e-mail, i.e. offline, and to build a knowledge base to be offered to other customers as an additional service package. By using the adapted IDEATRIZ, it was possible to generate more ideas given the indication of more inventive principles for the resolution of contradiction A and −A, which were able to come up with ideas similar to those generated with the original IDEATRIZ: to fulfill the offline chat by email and create a knowledge base for scripting, thus confirming the possibility of using IDEATRIZ adapted for generating service ideas.

An example of the form for generating and resolving contradictions is presented in Fig. 5.9.

The fourth stage of the adapted IDEATRIZ was carried out after the workshop, which included the evaluation of ideas and multicriteria analysis by 2 independent experts. The result of the evaluation of the ideas is presented in Sect. 5.4. At the end of the workshops, participants were invited to evaluate the adapted IDEATRIZ along the same lines as the original IDEATRIZ was evaluated to obtain a comparison from the same evaluation criteria.

5.2.5 Analysis of the Application of Adapted IDEATRIZ

The application of the adapted IDEATRIZ methodology was also carried out in workshops that began with an introduction to the concepts of innovation. At the end of the workshops, participants evaluated the adapted IDEATRIZ methodology and reported suggestions and difficulties by completing the same form answered by the participants who used the original IDEATRIZ. Participants answered 40 forms, where 10 suggestions were suggested to improve the use of the methodology.

Regarding the criterion "Degree of Difficulty of Understanding Methodology": none (0%) of the participants indicated it as high; 47.5% of them pointed it as of medium difficulty level; 35% mentioned it as a low degree of difficulty and 17.5% did not find it difficult. Regarding the criterion "Degree of Difficulty Finding Analogies for services", only 5% indicated that they had high difficulty in this criterion, 32.5% indicated average difficulty, and most participants, totaling 62.5%, pointed out that it found none or found little difficulty in making analogies to the generation of service ideas. Regarding the criterion "Stimulating interest in innovation", the methodology stimulated medium or high interest in Innovation in 85% of the participants.

FORMULATION OF CONTRADICTION A and -A	SEPARATION PRINCIPLE USED	INVENTIVE PRINCIPLES INDICATED
Feature that should be and should not be available at the same time CHAT ONLINE	IN TIME	#15 Dynamicity #10 Prior action #19 Periodic action #11 Prior protection #16 Partial or excessive action #21 Rushing through (Skipping) #26 Copying #18 Vibration (Resonance) #37 Expansion and contraction #34 Rejection and regenerated parts #9 Prior compensation #20 Continuity of useful actions

INVENTIVE PRINCIPLE (IP)	GENERATED IDEA
#15	Use a chat robot
#10	Create a FAQ (frequently asked questions)
#19	... following too many ideas from the analysis of the inventive principles indicated

Fig. 5.9 Example of generation and resolution of contradictions with separation principles (Author 2016)

Most of the suggestions raised, totaling 80% of 10 suggestions, were more examples of method application. Suggestions were made to simplify the examples to abstract from the physical concepts of the original methodology (10%) and to use the direct association of heuristics with the inventive principles (10%). Only 7 participants described their difficulties. Most found it difficult to use the separation principles (71.4%), followed by the difficulty of using heuristics to propose ideas (28.6%).

Because the participants evaluate the use of the adapted IDEATRIZ, it is highlighted that:

(a) No participant had high difficulty in understanding the methodology. There was a balance between participants who had medium difficulty (47.5%) and those who had low or no difficulty (52.5%);
(b) Only 5% considered the “Degree of Difficulty Finding Analogies for Services” to be high and 22.5% found no difficulty in analogies.
(c) Most suggestions (80%) ask for more examples of methodological use and most difficulties (71.4%) refer to the use of separation principles to formulate contradictions.

5.3 Results of Research

The comparison of the results obtained was based on the response of the forms answered by the participants after using the original and adapted IDEATRIZ methodology and the experts' evaluation regarding the quality of the ideas generated using the original and adapted IDEATRIZ. Table 5.1 shows the results of the methodology evaluation criteria regarding the application of the original and adapted IDEATRIZ methodology.

By analyzing the indicator "Difficulty in understanding the original IDEATRIZ" and "Difficulty in understanding the adapted IDEATRIZ" methodology, a small gain (5.7%) was identified about the ease of use of the adapted IDEATRIZ, as a 2.9% reduction in the high difficulty in understanding the methodology (from 2.9 to 0%) and 2.8% increase in participants who found no difficulty in understanding the methodology (from 14.7 to 17.5%).

Comparing the degree of "Difficulty finding analogies for services" in the original and adapted IDEATRIZ, significant changes were found in the indicators. The high difficulty in finding analogies for services was reduced in the adapted IDEATRIZ compared to the original by 30.3% (from 35.3 to 5%) and increased by 14.6% (from 22.5 to 5.9%) of participants who did not find any difficulty in the adapted IDEATRIZ compared to the original. This shows that meeting the suggestions given by participants resulted in facilitating the use of analogies for services in the adapted IDEATRIZ. From the suggestions collected in the application of the original IDEATRIZ, 70% of these included examples of services, which were included in the IDEATRIZ adapted in the heuristics and inventive principles stage.

The "Interest awakened to innovation" brought significant values regarding the indicators of high and medium interest awakened to innovation for both original IDEATRIZ (67.7%) and adapted IDEATRIZ (85%). It can be inferred here that the ease of use of the adapted methodology obtained by the inclusion of service analogies resulted in greater interest in innovation by the participants in the adapted IDEATRIZ.

The results of the quality assessments of the 180 ideas generated by the original and adapted IDEATRIZ performed by expert E1 are shown in Table 5.2 and the results of the evaluations performed by expert E2 are shown in Table 5.3.

Through the analysis performed, the 82 ideas generated using the adapted IDEATRIZ obtained the highest quality score of 98 ideas generated by the original IDEATRIZ by 2.76% by expert E1 and 3.74% by expert E2. However, by analyzing E1 and E2, in some workshops, the isolated score of the criteria alternated higher and lower values between the ideas generated by the original and adapted IDEATRIZ. For E1, 6 out of 9 criteria evaluated were higher in the use of adapted IDEATRIZ. For E2, 4 of the 9 criteria were higher for adapted IDEATRIZ.

For E1 and E2, the criterion "relevance" was more significant in the composition of the average idea quality score, followed by the criteria "feasibility" and "novelty". The average representativeness of the criteria in the quality score of the ideas was constant, both in the result generated by the original and adapted IDEATRIZ.

Table 5.1 Evaluation of the use of the original and adapted IDEATRIZ

	% Difficulty in understanding the adapted IDEATRIZ		% Difficulty in finding analogies for services		% Interest awakened to innovation	
	Original (%)	Adapted (%)	Original (%)	Adapted (%)	Original (%)	Adapted (%)
Not found	14,7	17,5	5,9	22,5	2,9	5
Low	38,2	35,0	11,8	40,0	29,4	10
Medium	44,1	47,5	47,1	32,5	26,5	30
High	2,9	0,0	35,3	5,0	41,2	55

Author (2016)

Table 5.2 Evaluation of ideas quality generated by the original and adapted IDEATRIZ evaluated by E1

	Evaluation of ideas quality generated by the original and adapted IDEATRIZ by E1							
	Average score							
	HOTMILK		UTFPR		BEPID		All	
Criterion	Original	Adapted	Original	Adapted	Original	Adapted	Original	Adapted
Novelty	4,20	3,91	3,81	4,32	4,11	4,54	4,04	4,19
Feasibility	4,25	4,49	4,41	4,45	4,54	3,75	4,43	4,30
Relevance	5,15	5,42	5,07	4,90	4,37	4,92	4,79	5,13
Idea quality score	**13,60**	**13,81**	**13,30**	**13,68**	**13,03**	**13,21**	**13,26**	**13,62**

Author (2016)

Table 5.3 Evaluation of ideas quality generated by the original and adapted IDEATRIZ evaluated by E2

	Score of ideas quality generated by the original and adapted IDEATRIZ by E2							
	Average score							
	HOTMILK		UTFPR		BEPID		All	
Criterion	Original	Adapted	Original	Adapted	Original	Adapted	Original	Adapted
Novelty	4,10	4,05	4,00	4,48	4,43	4,17	4,21	4,21
Feasibility	4,90	5,47	5,15	6,06	6,29	6,08	5,57	5,81
Relevance	5,20	5,77	5,19	6,23	6,46	6,42	5,73	6,07
Idea quality score	**14,20**	**15,28**	**14,33**	**16,77**	**17,17**	**16,67**	**15,51**	**16,09**

Author (2016)

5.4 Discussion and Conclusion

Using IDEATRIZ's direct application for service ideation in the workshops generated 98 ideas for Online Consultancy service improvements. Thus, it was proved that it is possible to use the direct application of the original IDEATRIZ for the ideation of services.

The key points in the suggestions and difficulties encountered in using the application of the original IDEATRIZ direct methodology contributed to the creation of the adapted IDEATRIZ, whose application generated ideas with higher quality than those generated by the original IDEATRIZ by the evaluation of two Online Consulting experts, area in which ideas were generated. There was an increase in the quality of the ideas generated by the adapted IDEATRIZ that confirms the second part of the hypothesis previously established when the research was proposed: that IDEATRIZ Methodology for product ideation (de Carvalho 2011) could be used for service ideation. But if it were adapted for services it would generate better quality ideas regarding the direct application of IDEATRIZ Methodology.

The possibility of direct use of a product ideation methodology for service ideation, in a generalist context, can be explained by the line of Gallouj and Djellal (2011) who identified that the product and service limit is undefined, given the growth in the offer of solutions in the product-service line integrating the development of new services (NSD) and new products (NPD).

The improvement in the quality of the ideas was not significant (2.76% by the expert E1 assessment and 3.74% by the expert E2 assessment), but other gains were obtained, such as the reduction in the difficulty of using the adapted IDEATRIZ methodology and a major reduction in the difficulty of making analogies for services. The inclusion of service examples in the heuristic stage and the inventive principles resulted in the generation of ideas and increased interest in the participants' innovation.

The gain obtained by the research was to open the field of using IDEATRIZ for service innovation, proving the possibility of using IDEATRIZ in the service area. Services are becoming increasingly important for the economy where service innovation can occur in many sectors, both in manufacturing and agriculture. Another major contribution of the research was the creation of the adapted IDEATRIZ that facilitated the use of the methodology bringing abstraction to the participants by the inclusion of examples for services, which resulted in the improvement of ideas and the awakening of the stimulus of greater interest to innovation, adding to the literature research on reinforcing creativity in the planning phase of service innovation.

As a proposal for future studies, research may evolve and become a practical guide to the ideation of services. This should include a larger number of practical step-by-step examples for formulating and resolving contradictions with the principles of separation (suggestion raised by participants after practices using the adapted IDEATRIZ) and can be collected and compiled as new examples of heuristics and inventive principles so that the adapted IDEATRIZ methodology is maintained for reference by Brazilian academics and entrepreneurs. The methodologies of Gazem and Rahman (2013) and Kim and Park (2012) could be applied within the scope of the IDEATRIZ study adapted for services to compare the use of methodology and quality of generated ideas.

In IDEATRIZ, created by de Carvalho (2011), the resolution of contradictions is performed using the Separation Method (for the same parameter) and using the Inventive Principles Method (for different parameters). The Inventive Principles Method includes the use of the Contradiction Matrix, the 39 engineering parameters, and the 40 Altschuller invention principles. The Altschuller contradictions matrix was generated from the result of the patent study to solve engineering problems and its direct translation to services and examples of its application has not yet been validated in the literature for use in services. Another line of study for research evolution would be to validate the possibility of including in the IDEATRIZ which adapted the solution of contradictions of different parameters by the Inventive Principles Matrix from field practices, survey, and compilation of results.

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Chapter 6
Problems in the Spreading of TRIZ in Argentina

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Abstract The foundation of professional training with only basic knowledge is being overcome. This has also become a trend in Latin America and is spreading to education in general. Regarding technological aspects, an engineer must have the capacity to creatively solve the problems related to his profession, and this is the current trend. As we will see, there is no consensus as to how to travel this path. We believe that structured methodologies, such as the Theory of Inventive Problem-Solving known as TRIZ, are the path to follow, but as we will see, they are little known in Argentina and other countries. Regarding the education of scientists and engineers, our advice for the short term is that they should be knowledgeable in basic polytechnical concepts and be able to use all the tools that scientific and engineering problem-solving theory provides. This model of superior education would help to overcome the historical barriers to the development of our industry, and surely, with the resulting benefits of having competitive professionals in the engineering sector, and to the economy and the standard of living of the population in general. We will deal with the reasons, mainly historical, why the implementation of TRIZ in our country is so difficult, and the lack of interest shown in many sectors toward innovation, a term much in style but poorly applied. This, added to the fear and a great rejection of the unknown and of taking risks leads us to being trapped in a "security zone" where no risks are taken, and being dependent on whoever dares to innovate and does take risks. We will see how, gradually, Argentina is joining the world on this issue. Specifically at the UTN Pacheco University, where the course "Methodologies for the Creative Development in Engineering" (a part of the Mechanical Engineering curricula) stresses the importance of problem-solving, teamwork, and intercommunication between different teams. Unfortunately, there are few, if any, references to

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TRIZ in Argentina. We are also committed to inviting other universities to join us in disseminating TRIZ in our country.

Keywords TRIZ in Argentina · Engineering problem-solving · University · Structured methodologies · Innovation

6.1 Problem-Solving

Future engineering professionals will have to join the productive field of goods and services with a solid knowledge of scientific and technological advances, with the purpose of applying them successfully to new developments (Reza et al. 2006).

Nowadays, society is demanding more from Universities (Sosa 2017); not only does it require professional training ("knowledge"), but also the provision of professional skills to its graduates ("know-how"). This is clearly seen and is thus assumed by the universities, especially from the Bologna Declaration of 1999 and the declaration of "education as a public service" of the Salamanca Convention of 2001.

It is also required by the guidelines for evaluation and the accreditation of the engineering degree of the Federal Council of Engineering Deans (CONFEDI) of Argentina and by the National Commission of University Evaluation and Accreditation (CONEAU), of Argentina, to evaluate careers, which determines the hourly load dedicated to problem-solving. In the words of CONFEDI, "There is consensus that the engineer must not only know but also know how to do." No one has doubts anymore that the engineer solves problems (Perissé 2019).

Having the competence to solve problems is an indicator of the quality of professional training carried out by an institution. A graduate who knows how to solve problems has an added value and, consequently, this competence legitimizes his or her quality and the quality of the training offered by the career he or she has completed, and the degree of engineering granted by a university in Argentina. At the same time, it makes a difference with respect to the universities of the other Mercosur member countries.

The old paradigm of professional training based on teaching as a simple knowledge transfer scheme that the student will know how to abstract, articulate, and apply effectively, has been losing space in the current reality. The know-how does not arise from the mere acquisition of knowledge, but it is the result of the implementation of a complex structure of knowledge, skills, abilities, etc., which needs to be expressly recognized in the learning process so that the pedagogical proposal can include the activities that allow its development". The lives of today's students are very different from the lives of the students for whom the existing education systems were developed.

Among the characteristics that should be sought in the Ibero-American engineer, one stands out for our case: The ability to analyze, model, experiment, and solve design problems, open solutions, and a multidisciplinary approach. Regarding the Professional Dimension, one of the competencies formed in this dimension is the engineer will have the ability to creatively solve the social problems related to his profession. This can be achieved by teaching, causing a process of self-reflection and investigation with the certainty that the concept of "problem-solving" can no longer be implied. The development of creativity is presupposed, which is not about creativity in the aesthetic or ornamental sense but in the sense of responding to a unique, unrepeatable, particularized situation, for which known technical solutions provide knowledge that only partially realize some of their variables. In keeping with this concept, generally the "What to do" is recognized, but hardly the "How to do it".

The solution to problems of interest for the evaluation and accreditation process is not reduced to the performance of exercises. In formal education, performing exercises to standardize procedures and consolidate knowledge has often led to the identification of the resolution of exercises and problems. But the resolution of exercises strengthens the convergent aspect of problem-solving by applying algorithms or establishing analogies with previously known and often standardized resolution models. However, how is it done when solving a problem demands divergent thinking?

It is often stated that the problem to be solved must be a real problem so that it can be verified that the answer is efficient. If the situation is not problematic for someone, there is no problem resolution because, strictly speaking, there would be no problem. The calling motivation must be highlighted. Generally, for problem-solving, a strategy is applied with the following steps:

- Defining the problem through the analysis of data or information,
- Exploring the problem by means of identifying its parts and through categorization.
- Plan the actions to solve the problem.
- Execute the actions and
- Check if the obtained results are consistent with those expected.

These five steps are only a general strategy. As a professor, the following questions arise: what are the techniques, the actions I must take to solve problems in my subject? What do students have to do? Then, there seems to be no other way for the professor concerned with problem-solving than to solve his own problem: how to convert the general problem-solving strategy into specific actions in the face of specific situations or themes. But, with what techniques? With which didactic design? The techniques, in this sense, intellectual resolution procedures, understood as thinking procedures, combine algorithmic methods with heuristic methods. Here appears another difficulty. It is known that algorithms are identifiable, encodable, and support secure transmission procedures. But heuristic procedures do not admit this precision since their effectiveness is defined by the creativity with which the subject formulates some questions or invents its proposals to solve the problem. They refer to an art, and in this sense, to the expertise, to develop strategies to invent answers, to the creative ability of the person who manifests in their work, in the experience with which they face problematic situations. Epistemologists have shown that this is a serious problem when it comes to knowledge production because rules cannot be established to ensure the discovery of new scientific theories.

The resolution of problems of different types and cognitive levels arouses curiosity, stimulates interest in learning, and in finding the best response to a new approach, while developing the skills of higher-order thinking, effective communication, teamwork, the search, and the analysis of information, among others. However, the experience can lead to impulsivity by performing mathematical operations and a traditional framing in the process. This psychological inertia must be detected and corrected since problem-solving does not imply the simple memorization of concepts, experiments, formulas, resolution algorithms, or impulsivity through numerical calculations.

In STEM education (Science, Technology, Engineering, and Mathematics), problem-solving is a central element because it favors the participation of students in their learning process, which becomes even more meaningful and profitable if such problems relate or connect in some way with real-world situations and, are more effective when they encourage students to transfer ideas across multiple disciplines. However, to ensure that students make connections among the scientific concepts studied and develop skills during the process, it is necessary that the professor keeps in mind the translational model (Cartagena et al. 2017).

It should be noted that the environment in which STEM activities are developed should allow the free exchange of ideas among students and encourage learning from collaborative activities. To achieve this, attention must be paid to the organization of the space, so that students can move freely among peer groups. This context facilitates the exchange of ideas and enables faster socialization of the achieved solutions, boosting the student's motivation when the goals are met.

Regarding this aspect, it is very clear the "What to do" Although it is not the case when it comes to the "How" To solve problems. The response to this demand, in societies such as China and Europe, seems to come from introducing TRIZ into elementary, high school, and university education systems. The question we could ask ourselves is: what did these societies see in the TRIZ methodology to organize educational systems and implicitly include TRIZ?

One possible answer may be that TRIZ is a means by which individuals are trained in inventive problem-solving skills and that, when going through the process of finding a solution to a problem, it is necessary, for example, to transcend learned theories and begin to put the acquired knowledge to work. With TRIZ, we begin by going through a path of search, process, analysis, and finally an acceptable pragmatism when we materialize the response to the problem, where there is no single solution but a field of possible solutions. From the TRIZ perspective and its derived methodologies, structures are used to solve problems, because, with their algorithms, formulas, and thinking strategies, they perfectly complete the How! Although this is widely ignored, especially in Argentina and, in general, in Latin America.

China has been the largest country in terms of engineering teaching scale in the world (Fan et al. 2012). The Engineering Training plan of Excellence (TPE) that they launched in 2010 is the training of various types of high-quality engineers and technical personnel who have strong innovative capabilities and meet the needs of economic and social development. The theory of inventive problem-solving (TRIZ), as a scientific methodology for solving innovation problems, offers a theoretical and practical guide for the training of engineers of excellence. This presents a fundamental difference with respect to Argentina and can be said for Latin America. Strength is made in the How! and in addition to the What! and for this, the educational reform and the development and talent plan of the People's Republic of China Ministry of Education development program have launched the TPE plan whose main objective is the training of a large number and various types of high-quality engineers and, technical staff that has strong innovative capabilities to meet the need for economic and social development. Undoubtedly, the Chinese perceive that the engineer's training of excellence also requires the innovative methods of TRIZ. Perfectly deployed the How to do!

According to the experiences abroad of the introduction of TRIZ in the study program, the TRIZ application methodology in higher engineering education in China would be an effective way to develop student creativity and innovative skills. Therefore, in 2009, the Ministry of Science and Technology of the People's Republic of China began to introduce TRIZ for training, and the objective is to improve the innovation capacity of Chinese scientific and technical personnel. TRIZ internship experiences in foreign universities and industrial applications indicated that TRIZ has played a catalytic role in reducing the development cycle of new and original R&D products and improving the efficiency of innovation. STEM education integrated with TRIZ.

But the Chinese understand that in many universities in China the TRIZ methodology is not yet understood and could barely integrate with professional courses. Consequently, universities should give importance to conducting TRIZ research and training classes, and encourage professors to participate in TRIZ practice, interdisciplinary research activities, and industrial technological innovation through an innovative TRIZ platform and university-industry cooperation in research. In our opinion this is what should be deployed in the universities of Argentina and Latin America.

The practice of applying TRIZ for engineering higher education reveals that the TRIZ methodology significantly improves the engineering and innovative capabilities of students. Develop a standard teaching and training system for TRIZ, which has its own logic and regularity. Thus, developing a standard training system, such as platform training and software, can greatly improve the efficiency of knowledge dissemination and the effectiveness of teaching.

The knowledge and ability to apply creativity tools are the same for all areas of science and technology. Apparently, in the future, emphasis will be placed on the education of scientists and engineers who have basic polytechnic knowledge in conjunction with the perfection of mastering the tools of the theory of scientific and engineering problem solving (Yevgeny 2013).

Meanwhile, on the agenda is the problem of using the similarity discovered in the basic mechanisms of scientific and engineering creativity to reflect the high potential of TRIZ in a similar theory of scientific creativity.

In the above, it is observed that, practically in all of Latin America, it is spoken exhaustively as a great advance, by the way, that it is, in the educational systems of the classrooms, especially engineering, of the ¡What! but the how! It is always diffuse. Although a general 5-point scheme is shown, which shows a certain ordering of steps to follow, it does not configure a structure such as TRIZ and its derivatives, such as SIT, USIT, TRIZICS, etc., described later.

In Argentina, little has been done so far in the classrooms, especially in university and engineering regarding the teaching of TRIZ. In the UTN FRGP (National Technological University General Faculty Regional Pacheco) in the academic unit of mechanical engineering to relieve this situation of the current needs of our country through the implementation of an annual elective subject called "Methodologies for the Development of Creativity in Engineering", in which the TRIZ methodology is taught and applied to real problems. It turned out to be very accepted by our students. This represents a breakthrough in the training of future professionals because if they work under a dependency relationship "the employer pays salaries to solve problems and if he is an entrepreneur, he must only solve problems, whether technical or management. Subsequently, the subject on "entrepreneurship" was introduced and in the very near future classes on rapid prototyping will be taught, with the above-mentioned including Design Thinking (DT) taking into account the empathized design for the human being we can complete and answer what and How to solve problems? Well, any development, especially technological, are a great chain of problem-solving. This will enable TRIZ to be integrated into other tools and methods, which is the way to use TRIZ.

TRIZ can contribute to the training of professionals by breaking their psychological inertia and approaching examples of solved inventive problems, which resemble the innovation model. The TRIZ methodology trains the professional to develop the intellectual effort to find a solution to an inventive problem with a discipline that is not obtained through a random process of trial and error, but with systematic planning and effort.

We do not have information on the teaching of TRIZ in Argentina in this way. However, there are short and simple courses, rather informative than formative for applications in solving problems.

As it is observed, there is not yet in Argentina, at least in the knowledge of these authors, formal sites, or authoritative sources for learning TRIZ, the importance of the How! to solve problems in a structured way (TRIZ and derivatives), as well as too much interest in delving into these issues. The fact that only knowledge is guaranteed the success of problem-solving, inherited by an old and outdated conception of formal education and the lack of formal understanding also depends on the employed strategy and the attitude to face them. These are the consequences of systematic innovation, and training in a subject that practically does not exist in the country. If we look on the page of "MINCyT (Adler 1988) Library", the word TRIZ until a short time ago only took us to an eBook format, very good, which is the book of Michael Orloff (Narasimhan 2006). It also recommends where to buy it. Less installed is the fact that with structured methodologies solving technological problems is a real pleasure and not a tedious heavy load.

The professor at the university level generally does not have the required professor training, we could say that he is a self-taught agent who develops his educational skills by accompanying another professor with more experience or through trial and error.

Since the offer of training on TRIZ for professors is more than deficient, the adoption of this methodology in Educational Institutions and the generation of experts in the subject is complicated. Not to mention that it is a technique that recently landed in Argentina, so the few human resources that have been trained in the subject are understandable.

As we have expressed, at present, for most professional training, what the professor does is transmit information from the books. A large part of what is currently taught is the transmission of information or instructions to handle certain techniques. That is why, as Pérez Lindo (2017) indicates, the professor's new role will be to teach how to learn to think, communicate, work as a team, live together, solve problems, to design projects. This means that a new era of higher education should be entered.

In 2011 according to the data of the University Statistics of the Ministry of Education. 113,664 university professors are available. If we analyze the structure of university teaching positions at national universities, we can see that in 2011 there were 159,898 positions of which: 103,617 were of simple dedication, 30,219 of semi-exclusive dedication, and 20,323 of exclusive dedication. So, the number of professors fully dedicated to research and teaching does not exceed 20%. 60% of university professors work in simple dedication positions and earn much less as university professors than most qualified employees in the industrial, banking, among other sectors. This makes teaching relegated to a second profession, not being the main one of his professional life. So, the time dedicated to it is subject to the remaining time that the professor has in his main activity since this is his main source of income. Due to the need to have another job, the time devoted to professor professional training is limited. Analyzing the academic profile, in the Yearbook 2011 we found that the number of professors with a doctorate reached 10,269, that is, only 9% of all professors. The time they can devote to the application of new methodologies such as TRIZ in training is nil.

The most important intellectual capital of any company, employees, can be greatly increased if they learn the application of TRIZ, to face problems of inventiveness or technological innovation, contributing to the success of the company. Nor is there any awareness that all organizations can innovate and do so systematically, without relying on an individual expert, who, for the sake of fate, is in the organization. TRIZ allows the generation of ideas of conceptual solutions without being an expert in the subject since it consists in using, in some way, the maximum available knowledge on a specific problem and arriving at a space of solutions for the adaptation of solutions previously applied to similar problems.

6.2 Brief Tour of Several Structured Engineering Problem-Solving Methodologies for Engineering Application

This brief tour aims to show the different structured methodologies for solving engineering problems. The present authors adopted, in accordance with what has been studied and their own experience, classify them from the structured as unstructured, the latter being well known and widespread, such as Trial and Error, Brainstorming, Lateral Thinking, etc., of which there is abundant information and reference materials and ways and places of teaching and learning. There are many experts who can give an excellent account of these methodologies.

According to our classification, they follow the semi-structured methodology in order, which we have thus classified given their characteristics. By this, we mean the very little-known, outside of Japan, methodology of Equivalent Transformational Thinking (ETT).

If we develop, in terms of structured methodologies, an exhibition of these based on the "Great Russian Mother" of all of them, the so-called Russian acronym TRIZ. From it, we will see how others derive, which, will be briefly described later. A classification, we believe plausible, of the methodologies for solving engineering problems is to perform them according to their work structure.

Unstructured methodologies such as "Score", Lateral Thinking, Heuristic Method, "Brainstorming", Morphological Analysis, Synectic, etc. (Grudner 2014), despite being handled based on specific techniques to its management, in contrast to the so-called structured methodologies, they are called Unstructured Methodologies, because it is very random, a situation that does not support structured calls.

Unstructured methodologies are numerous (Nakagawa 2005), compared to structured ones. As for the PTE, as a methodology that we "baptize" as semi-structured, it is a theory about the creation and innovation proposed by Dr. Kikuya Ichikawa (Kyoto University, then moved to Doshisya University) in 1955. It is practiced and tested by The Ichikawa School by professional engineers from the R&D and production sectors of the manufacturing sectors. Dr. Ichikawa led the school from 60 to 80 (HIBINO 1979).

Kikuya Ichikawa (1915–2000, Japan) tried to overcome the weakness of analog thinking and established a new scheme for creative problem-solving. He named his scheme "Equivalent Transformational Thinking." (Shigeta et al. 2011). Starting with the main purpose of this work, we will discuss structured methodologies beginning with the first methodology and generating others. We refer to TRIZ.

TRIZ is a methodology of Russian origin for solving inventive problems and being perhaps the first and only structured methodology, it is also the direct and indirect basis of all subsequent methodologies known to date. From these derived methodologies we will take the main ones. They are known as ASIT, SIT, USIT, TRIZICS, HI, etc. Necessary descriptions will be made about ASIT and SIT because they are important methodologies and were largely drivers of the USIT. We will also briefly describe the TRIZICS methodology derived from TRIZ.

In the development of the work, the reader will observe how the different methodologies have points of contact and feedback from each other. Such is the case of USIT and TRIZICS, where we will focus more and where the latter, which arises from directly from TRIZ, is strikingly close to some steps and philosophies of the USIT, older, which precisely also has part of its roots in TRIZ.

This creative problem-solving technique called “TRIZ Method” is unique in its conception since it arises from a different approach, which consists in using, in some way, the maximum available knowledge about a specific problem and reaching its solution for the adequacy of solutions previously applied to similar problems, taken from patent bases. With this, TRIZ is the first methodology that has been defined as “based on knowledge”, but not the only one, and in this, we refer to those already mentioned derived from the TRIZ methodology. In some of these derivatives, the creators try to shed the baggage of the information bases, to transform them into tools of thought.

There are two types of problems that the human being must face:

- With previously known solutions.
- With unknown solutions.

Those problems with known solutions can usually be solved with information obtained from technical texts and specialized publications, also by consulting specialists in the field in question. In the case of unknown solutions, what was mentioned above does not follow that path, it does not exist. TRIZ helps us to invent that path in a structured and not random way because the problem is raised towards a standard problem of a similar or similar nature. A standard is known and from this will come the solution.

The solution to the problem can be reached very quickly, a situation that is very unlikely, or most likely, the path to the solution has a very random, hardly reproducible component. Unstructured methods have a strong component of psychological inertia, that is, resistance to free creative thinking due to unconsciously imposed barriers, it is a certain “stagnation” due to human programming, being guided by their habits. Psychological inertia represents the many barriers to personal creativity and the ability to solve problems (Nishiyama et al. 2018). This is radically avoided with structured methodologies. Structured methods do not reach a solution but instead reach solution spaces.

After the fall of the Berlin wall, Genady Filkovsky, a student of Altshuller, took his ideas to Israel. Genady found a position at the Open University, and she continued to develop a modified version of TRIZ. Genady Filkovsky’s work after leaving Israel was continued by two of his students: Roni Horowitz, from Tel Aviv University, who learned about TRIZ in 1998 in a course taught by Filkovsky, and Jacob Goldenberg, from the University of Jerusalem. In 1990, Dr. Roni Horowitz began teaching the TRIZ method together with his colleague Jacob Goldenberg at the Tel Aviv Open University (Sickafus 1997). During the courses, he observed the difficulty that many people have in putting the method in motion and concluded that it was necessary to modify it to be more user-friendly. At the same time, he begins to investigate and apply the method as a doctoral student at the University of Tel Aviv under the direction of Professor Oded Maimon. They made Altshuller's original method more effective, simpler, and easier to learn. At first, it was used to solve technological problems, but with the advancement, in research, it became clear that the ideas on which the system is based are universal and can help in the search for creative solutions in a variety of fields. Horowitz and Goldenberg teach the current version known as Systematic Inventive Thinking (SIT). To adapt this method to computerized teaching and practice, they developed the Advanced Systematic Inventive Thinking (ASIT) method.

Horowitz derived ASIT from TRIZ in four steps (Horowitz 2001). Therefore, ASIT should be seen more as a complement to TRIZ than as a substitution. Another methodology derived from TRIZ is the recent TRIZICS, which is a structured problem-solving methodology, which serves to find innovative solutions to technical problems. TRIZ has a reputation for being difficult to use. We have already seen several attempts with greater or lesser success to overcome this difficulty in trying to simplify TRIZ for the user. TRIZICS is also another attempt, but to our knowledge, successful.

TRIZICS, being recently created, is not yet well known. It provides to whom it solves problems, in addition to the TRIZ tools, extra (non-TRIZ) troubleshooting tools, and a framework that allows applying the classic TRIZ tools in a systematic and sequential way to the technical problems, which are classified into four types of problems. That is, instead of reducing the tools of TRIZ, TRIZICS provides an additional framework and tools for TRIZ, simplifying its use. TRIZ becomes a subset of TRIZICS. It was created by Gordon Cameron between 2007 and 2011 (Cameron 2010).

Unlike Classic TRIZ, TRIZICS can be used for root cause analysis. The TRIZICS methodology comprises six basic sequential steps:

- Identify the problem (problem definition)
- Select the type of problem
- Apply analytical tools
- Define the specific problem(s)
- Apply Solutions Tools
- Identify and apply solutions.

Another tool derived directly from TRIZ and indirectly from TRIZ, through SIT Sickafus (1997) and ASIT of Israeli origin is the USIT (Unified Structured Inventive Thinking) is a structured problem-solving methodology. It has been developed and tested in the industries to assist the analyst in the definition, and subsequent analysis of problems, leading to the application of specific solutions techniques and expanding the search for conceptual solutions, based on a small set of unified components that make up the OAF Model (Objects, Attributes, and Functions), logically concatenated. Ph.D. Ed Sickafus, the creator of the USIT, took part in all these structured methodologies to design the USIT.

Within the framework of the USIT, the "desired effects", the useful ones, receive the special name of "functions". Therefore, both words, function, and effect, carry the connotation of an action to modify or maintain (Sickafus 1997).

The word "cause" is used in the analysis of an unwanted effect. First, it is determined whether the unwanted effect is a unique unwanted effect—the main topic of discussion in defining the problem for the application of the USIT. Therefore, by analyzing an unwanted effect in terms of its causes, other entangled effects may become apparent. Function, Effect, Unwanted Effect, Cause, and Root Cause, are terms that have equivalent relationships, at least in USIT, and all of them have associated attributes. These are referred to as causal attributes when referring to causes of unwanted effects and as supporting attributes when referring to functions. By listing the causal attributes to be associated with each of the root causes, a diagram of the credible root causes is completed. In short, discriminating the words cause, root cause and effect is as follows: an effect maintains or modifies an attribute.

The OAF model of the USIT consists of a pair of interacting attributes, one of each from two objects in contact. That is why the cause of an effect can be described in three different ways: in terms of another effect (or function), in terms of two interacting attributes, or in terms of two objects in contact. This model helps the analyst to focus on the point of contact between two objects and to identify the active contact attributes mentioned and allows insertion into the USIT Flow Diagram.

USIT, like the other structured methodologies, does not seek the solution to the problem but begins with defining the problem, making its subsequent analysis, and then just applying solution techniques and falling into a space of solutions. TRIZ works based on a large database, the SIT, on the other hand, is a simplification of TRIZ, an excellent pocket tool to solve problems, but not so powerful. USIT, in the opinion of the authors of this work, takes the best of each of these methodologies. That is the power of TRIZ and the simplicity of SIT. It is a purely thinking tool that dispenses with the monumental TRIZ database. Much of that is due to its OAF model. It should be added that, while TRIZ is an excellent tool for creativity and innovation, USIT is in terms of problem-solving, which does not imply that both methodologies cannot be exchanged between the mentioned circumstances. In 2012, TRIZICS is presented, a tool that looks like a mix between TRIZ and USIT. It was created by Cameron Gordon, TRIZICS, and, like USIT, has very well limited and pointed out the issue of the Root Cause of the Problem. The latter situation exists in TRIZ, but rather implicitly.

Another structured tool after TRIZ, with many things in common, since it also starts from patents, that is, from situations that have solved problems is 121 H. This name refers to the 121 Heuristics of Polovinkin.

It is convenient here to clarify that heuristics can be rules, strategies, principles, or methods to increase the effectiveness of solving a problem. The heuristics provide neither direct nor definitive answers, nor guarantee a solution for a problem. They only provide an aid to point to an easy resolution of the problem.

Altshuller explored patent databases with the purpose of developing Heuristics for problem-solving with TRIZ. In his work, the levels of patents and the relations of the use of the Heuristics (and thus the probability of their use in the future) were taken into consideration. His famous group of 40 Heuristics known as Inventive Principles is helpful in finding solutions to many problems.

Less known is the set of heuristics selected by Professor A. I. Polovinkin (De Carvalho et al. 2004). They are derived from the best problem-solving practices by engineers and machine designers of the former URRS. These heuristics can be organized into groups that reflect changes in the main attributes of a technique, such as a form or material. They were selected based on the effectiveness of their use according to the frequency of their occurrence in the technical literature, although without appropriate statistical analysis. Polovinkin heuristics are universal and can be used to solve technical problems in different areas and in non-technical problems.

There are two main reasons why Polovinkin Heuristics are not currently widely used:

- Until this millennium they were published only in Russia, in “hard to find” books.
- There is a lack of examples that should make it easy to understand and prove its value in solving international practical problems.
- Savransky and other authors published in English the Polovinkin Heuristics from the Russian original for better dissemination; they even provided a set of examples from the database of international patents. They decided to reduce the initial set of Polovinkin Heuristics. The reason is that firstly, the original Heuristics reflect legal aspects of the engineering and safety design of the former URRS—hence, they cannot be used throughout the world. The second reason is that some of the original Heuristics are only important for the detail design stage.
- Another main objective proposed by Savransky and his collaborators on these heuristics was:
- Verify your assumption that the selected Heuristics are valid throughout the world.
- Test your hypothesis that the selected Heuristics are independently cultural.
- Verify your assumption that Polovinkin Heuristics can enlarge TRIZ’s knowledge base by comparing them with the Inventive Principles.
- Seeking simplicity, they called the reduced set of Polovinkin Heuristics as 121H.
- Many attempts to compile thumb or heuristic rules were made by the inventors to point out in the problem-solving guide to more promising solutions. Research methods vary according to the topics of study. In general, these methods can be classified by:
- Study the thought process followed by creative people in the development of their work.
- Study the product of creation despite the thinking process of the creator.

The first approach is very popular in Western countries and has led to significant developments, especially in Cognitive Science and Artificial Intelligence. The second approach—recently from the former URRS to several countries—has led to the development of TRIZ (Savransky 2000).

From our experience in problem-solving, we conclude the product based or as a TRIZ Heuristic has advantages over the Heuristics that were developed using psychological or cognitive approaches.

A. I. Polovinkin and his collaborators adopted a similar technique based on approaches to find Heuristics for transformation systems. However, they restrict the source of evidence for their former URRS researchers, where they sought highly experienced engineers developed solutions. It is possible to group the Polovinkin Heuristics into the following eight classes:

- Shape transformations (16 heuristics)
- Structure transformations (18 heuristics)
- Transformations in space (16 heuristics)
- Time transformations (8 heuristics)
- Transformations of movements and forces (15 Heuristics)
- Material transformations (23 heuristics)
- Convenience of differentiation (11 heuristics)
- Quantitative transformations (14 heuristics).

All of them are described with examples of patents in the literature based on a statistical study. The HI methodology (Sickafus 2004), which refers to the English acronym for Heuristic Innovation, was created by Dr. Ed Sickafus, who created, as previously mentioned, the USIT.

Heuristic innovation is an improvement on the methodology for the resolution of structured existing problems, problem-solving methodologies including the USIT, which was an improvement on the methodologies for structured resolution of previous problems. It is not that these methodologies are incorrect or inadequate. Rather it demonstrates something that as practiced, new ideas arise to simplify them. Many of the concepts used in USIT are used in HI. It should be clarified that we have positioned this heuristic issue here as a continuation of the historically previous ones of Polovinkin.

A detail to consider, these heuristics arise from the USIT, which does not have a database like TRIZ. Another tool is called "Glazunov Parametric Solutions" (Glazunov 1990). The basis of the parametric method consists in the analysis of the results of the elimination of what is called TRIZ Physical Contradictions and highlighting in them the object that meets its requirements. Very unknown tool in the west.

In conclusion, due to this brief incursion into problem-solving methodologies, the well-known unstructured methods such as Lateral Thinking, Brainstorming, Method of "Testing", Heuristic Method, Morphological Analysis Method, Synectic Method, etc., are unpredictable for the generation of solutions to complex Technological Innovation problems since they do not integrate a defined structured algorithm to provide viable solutions. They are very widespread.

More complete, in the opinion of these authors is the semi-structured method of the EET. When a man creates a new thing or concept that has gone through something common in a different thing; he searches for and captures an "equivalent type of relationship" in it. Equivalent Transformational Thinking is a very useful tool for creation and innovation, promoting analog thinking. Therefore, we consider that EET is a very useful and immediate "pocket" tool for the technologist as a previous step to going directly to structured methodologies. It adds to the "toolbox" of the technologist.

We want to leave open the thought towards the gestation of a possible unification of these methodologies into a single problem-solving tool that inherits the best particularities of each one of them. But for this, much remains to be done, then, TRIZ was not accepted enough to allow the "landing" of its derived methodologies, which provide improvements to TRIZ.

In most of these methodologies, the authors handle, use and make contributions to several of them together with different authors.

The EET has hardly left Japan. Structured methodologies derived from TRIZ as TRIZICS, have just begun to spread, SIT of Israel, spread in other countries, curiously entered Nicaragua from the hand of Cuban physicist Hugo Sanchez, and USIT widely used in Ford Motor Michigan reached Japan, South Korea and is also spreading in China. But there is still much to deploy in Latin America, well, TRIZ is just doing it and in a very incipient way.

6.3 Influence of Continuous Improvement at the Expense of TRIZ

In the previous century 90s, it began the implementation of continuous improvement in companies, which were foreign and from the automotive sector. Later, the large national companies were inserted adopting this. Modality after the implementation of the ISO9000 quality assurance system, as the Continuous Improvement technique was later added into the standard.

The multinational automotive companies of American origin are installed in Argentina under the QS9000 standard quality assurance system, which includes Continuous Improvement. The same happens in the APQP (Advanced Product Quality Planning) and LEAN Manufacturing.

Tools like AMFE (Analysis of the Failure Mode and its Effects) of system, product, and process, DOE Taguchi (design of experiment), QFD (deployment of the quality function), SMED (rapid change device), Poka-Yoke (mistake-proofing), DFA/DFM (design for assembly and manufacturing), CEP (statistical process control), CP/CPk, VA/VE (value engineering and analysis), TPM (total productive maintenance), 8D (8 steps for solve problem) and others dictated by the AIAG (Automotive Industry Action Group) the implementation of the continuous improvement in the product/process was deployed to the auto parts suppliers.

With the Establishment of Toyota in Argentina, the Toyota Production System was implemented to all supplier partners as well, the design of which must be thought of continuous improvement (Kaizen) and served as a sales argument, which was described in the previous paragraph.

Subsequently, SMEs introduced these concepts slowly, being very reluctant to implement the new methodologies that involve fundamental mental changes. Subsequently, it was tried to implement 6 Sigma and today industry 4.0 is incipient.

As usual, multinational companies in Argentina take all the initiatives to implement the new techniques which are products of their parent companies. Few cases of national companies have enough motivation to implement new methodologies.

The reason for this is that many entrepreneurs, from experience, know that there are unscrupulous professionals who offer technological innovations without having the appropriate knowledge and appropriate academic levels as a panacea for the solutions to their technological problems, such as simple magical solutions.

For these and other reasons, the implementation of TRIZ is very slow because psychological barriers must be overcome, such as the acceptance of the continuous improvement, and that; in addition, TRIZ is much more complex than the previous ones. TRIZ allows the change of the Status Quo, on the other hand, the continuous improvement is the continuation with the same Status Quo, it is evolutionary, and it is an incremental short step, not an incremental jump as one given with TRIZ.

6.4 Entrepreneurship—UNDP Project (United Nations Development Program)

UNDP is a program to strengthen the development of systemic, social, and cultural conditions for entrepreneurship. Our faculty (UTN FRGP) was appointed to carry out this project, through an agreement signed between SEPYME (Small and medium-sized entrepreneurial secretary) under the Ministry of Argentine Production, the National Technological University Regional General Pacheco Faculty and the General Pacheco Foundation creating the Entrepreneurs Club "Tigre", aimed at promoting entrepreneurial activity and innovation through collaborative work, providing training, sensitization, and training services in productive development for innovation and promotion of different socio-economic sectors.

This project fortifies the development of social and cultural systemic conditions for entrepreneurship with the purpose of contributing to the creation of new companies and granting the tools that make their stability, profitability, and sustainable productivity. For this, actions are carried out that promote the development of an approach focused on the promotion of entrepreneurial culture, the expansion of social capital, human development, the consolidation of institutional schemes, and the strengthening of entrepreneurship based on the value chain with social impact. And access to financing. On the other hand, in the faculty of the undergraduate degree we have an annual elective subject referred to as entrepreneurship, we consider by empathy with this club of entrepreneurs, it is enhanced with the students already studied this subject and above all with students who have completed TRIZ.

However, we believe that in the coming years we will intensify by giving talks focused on the structured resolution of a problem with TRIZ. This is intended to achieve a great competitive advantage.

6.5 Argentine Economy and Industry (1810–2018)

Between 1860 and 1930 the greatest economic pushfulness is registered for the territory where Argentina is established today (Rojas 2003). Seventy years of growth, modernization, democratization, and relative political stability. Millions of European immigrants sought a better destination in Argentina. The fertile soils of the pampas tempted European markets thanks to the railroad and transoceanic vapors. However, the country would end up sinking into a deep crisis.

Five stages of varied growth are recognized in Argentine history from independence to the last century:

- Colonial period and emancipation.
- Agro-export model between 1860 and 1930.
- Industrialization by importation substitution from 1930 to 1975.
- The neoliberal model.
- Post-convertibility.

6.5.1 Colonial Period and Emancipation

In the Argentina in the 16th and 17th centuries, "The land of silver" there were no precious metals, nor abundant indigenous labor for the Spanish conquerors. The cattle, mostly semi-wild, quickly expanded through the pampas due to the non-existence of predators, the semi-temperate climate, and good pastures. Because of this, large ranches were established during the 17th century, mainly in the interior of Buenos Aires.

Since independence, in 1816, and the beginning of the agro-export model in 1860, livestock activity is under a landowner modality with an incipient agricultural activity. The industrial sector, already outdated, was based on manufacturers mostly of foreign origin. In the interior of the country, there were only small industrial craft workshops that had been developed under colonial trade. With independence, the supremacy of Buenos Aires and its promoted trade policies put regional economies in crisis and unleashed centrifugal forces, the national unification in doubt more than once.

6.5.2 Agro-Export Model Between 1860 and 1930 (Commodities)

Between 1840 and 1860, ovine cattle were greatly increased and with it the export of wool and by 1880, the growth was overwhelming. The standard of living in Argentina, at the beginning of the First World War, exceeded most of the Latin American countries. By then, the Argentine elite had little interest in creating industries;

Agro-livestock was much more profitable and industrial production required technical knowledge, experience, and organizational talent, generally foreign to those elites and the urban middle class. In addition to that, foreign investors-oriented industries towards exports, while immigrants engaged in industrial activities for the domestic markets, which, already in 1914, were characterized by an intense spirit of work, a little sophisticated base knowledge acquired through personal experience in commercial or industrial activities in your home country, and very limited economic resources. It turned out a small replica of the Industrial Revolution of the eighteenth century in England. The Argentine industry was born one hundred years behind and dependent on the process of production and knowledge and foreign technological innovation. Therefore, business associations called for state protectionist political interventions to curb competition from imported products. The domestic market grows due to the demand of cities and population growth. The production of goods with natural barriers to export such as cement and bricks, and the production of mass consumption goods associated with local tastes and preferences (in the food, textile, and chemical sectors) stand out.

The revolution in maritime transport and food refrigeration boosted the commercialization of meats and, already in 1930, exported food products surpassed countries such as the United States and Canada. The railroads, of British origin, boosted the metalworking industry based on the demand for parts and pieces for the railroad, which promoted from 1945 the training of human resources of excellence. The diversification of exports and markets was poor, and the scale of the incipient national industry was reduced. It depended on international prices and climatic avatars.

6.5.3 Industrialization by Importation Substitution (ISI) From 1930 to 1975

Since 1930, a country that believed in the future and in development was becoming "the frustrated country" and, later, the "desperate country" of recent times due to the fall in prices of primary products exported, particularly in relation to industrial goods, enabled some exceptional industrial development, limited by national productive capacity and the difficulty of importing machinery and other goods necessary for industrial production. In the early 1950s, almost all meat and grain production was for local consumption. In addition, the massive expropriation of export industry revenues by the government would finance much of the redistribution of income, public spending, and rapid industrialization, but, no more modern and oriented towards the most basic consumption and wage increases They led to accelerated inflation, with serious problems in the trade balance and strong import restrictions. It was a semi-closed economy, and below the standard of international productivity, which should be protected from foreign competition.

In the mid-1950s, Argentina moved towards technically more sophisticated products, such as vehicles, telecommunications, machinery, and other capital goods, but with little creation of its own technology and knowledge, which resulted in attracting multinational companies, dominating business activity with a politicized economy. It had little to do with the efficient use of resources in a technological sense and that generated corruption everywhere. Lawyers and people with influential family relationships and good political contacts were more important to companies than engineers or industrial organization experts.

Despite this, technical education is promoted with the creation of factory schools, the National Workers University with regional faculties (later National Technological University), and the National Council of Technical Education is created in 1959, favoring the development of technical capacities necessary for the industrial impulse.

In 1975, there was a brutal economic adjustment, known as the Rodrigazo, which doubled prices, with the aim of eliminating the distortion of relative prices. There was a shortage of food, fuel, and other supplies for transport. The ISI became necessary, and the main CyT institutions emerged from it. Although, there were already important creation precedents such as the National Council of Scientific and Technical Research—CONICET (1958), the National Institute of Agricultural Technology—INTA (1956), the National Institute of Industrial Technology—INTI (1957), the National Atomic Energy Commission—CNEA (1950)—and the National Commission for Space Research—CNIE (1960, current National Commission for Space Activities—CONAE). Despite this, the substitute policy and the impulse to science and technology did not achieve the link between the industry and the primary sector and between the industry and the CyT complex. The technological change between 1945 and 1976 was determined by the incorporation of external technology, a consequence of a protected domestic market.

6.5.4 The Neoliberal Model

It was implemented during the last military dictatorship and deepened during the 1990s. The forced break of the ISI comes with the coup d'etat of 1976, and until 2001, public policies reversed much of the progress of the previous half-century. From the government and the most orthodox academic circles, it was argued that the economy faced a mistreated primary sector, a rentier industrial sector, and an oversized state, which undermined the normal functioning of the market. The importation was opened, the State was reduced, the tariffs were reduced, and the financial system was reformed. In practice, it led to the consumption of imported products and financial speculation, as the internal interest rate increased along with devaluation expectations.

However, science and technology were understood as state policy. The Ministry of Science and Technology was created (until then with the rank of Undersecretary under the orbit of the Secretariat of Planning) as a dependency of the Ministry of Education. The Latin American Higher School of Informatics (ESLAI) was created and the democratization of CONICET was promoted based on the establishment of a subsidy system based on public calls, among the most relevant transformations in scientific and technological matters. Although the agricultural sector, achieved significant productivity increases with the adoption of transgenic seeds, direct sowing, and important changes in the forms of organization of agricultural activities, this technological advance was incorporated of external origin, without internal articulation.

The economy was opened to international competition, the foreign market was deregulated, sector regimes were renegotiated—essentially the automotive one—and the labor market was reformed. The foreign exchange policy aimed, in addition to curbing inflation, to generate positive expectations by anchoring one of the most important prices in the economy: that of the US dollar.

On the other hand, it was expected that the entry of technology via the importation of the capital market would generate increases in the productivity of the national industry, with a bit of optimism regarding the export output of manufacturing.

Within the framework of the law for the promotion and promotion of technological innovation regulated in 1992, the figure of the technological linkage units (UVT) is created. Then, based on a loan agreement with the IDB, the Argentine Technological Fund (FONTAR) and the National Agency for Scientific and Technological Promotion (ANPCyT) were created in 1994, including the Fund for Scientific and Technological Research (FONCyT) in 1996 with the idea of concentrating in this organism the functions of execution of the scientific-technological policy. In 2001, Argentina had become a financial black hole; external financing was completely cut, except for international rescue organizations such as the IMF.

Mercosur was formed as a free trade area, successful in the first years, quadrupling exports to Mercosur countries. But dependence on the Brazilian market would become disastrous when Brazil broke with the spirit of cooperation on which Mercosur rested and drastically devalued its currency, the real, in January 1999.

6.5.5 Post-convertibility

The social outbreak crisis of December 2001, with more than three years of poverty massive growth, high unemployment, and economic recession, was the evolution of decades of destructive redistributive conflict, populism, privilege hunting, institutionalized corruption, and increasingly violent conflicts, and growing instability. Initiated with the devaluation of the currency, 2002, characterized by a high exchange rate with withholdings on exports that favored the development of the domestic market and consumption.

The exit of the convertibility regime gave way to a new period of growth led by the rise of the international market based on natural resources and a new relative price scheme generated by the strong devaluation of the Argentine peso. As of 2003, the different exchange rate policies allowed the productive sectors to regain competitiveness and improve both the export performance and the capture of the internal market.

6.5.6 Consequences

In general, entrepreneurs have a low commitment to innovation as a competition mechanism, concentrating efforts on the acquisition of foreign technology. Innovative firms have reduced achievements and their relationship with the institutions of the innovation system, although high in terms of the number of links is weak in technology (Dutrénit and Sutz 2013).

The local and sectoral system is associated with capital goods such as agricultural machinery, closely linked to the production of intensive goods in natural resources. The automotive industry with a long history in the Argentine productive structure is important for the type of high-tech chains it can generate and for the labor force it employs. There are two systems linked to natural resources: soy and derivatives, and wines.

Constant relative price fluctuations for inflationary reasons cause entrepreneurs to devote all their efforts to controlling only finances. The semi-closed economy without competencies prevents cost reduction through innovations. Keeping the cash flow on the agenda is the leitmotif of the employer's survival, which in general, only thinks that the devaluation of the peso against the dollar is the best way to achieve the expected benefits. Developing new products with new and innovative technologies is risky to only satisfy the domestic market.

6.5.7 Result

A legacy of the colonial era, which has worsened over time, stimulated by an artificial bonanza generated by extractive industries, that threatens the production of material and symbolic goods since it reproduces the old: warlordism, personal or state paternalism, and hierarchical relationships, reinforcing the subordination of society. Meritocracy seems to be practiced, in general, only in private companies. This short-term policy leads to voluntarism in the formation of ideas and decision-making based on what is desirable or pleasant to imagine, rather than based on evidence or rationality. The lack of a culture of effort does not allow perseverance, tenacity, commitment, discipline, passion, and vocation, essential to achieve necessary changes and leave that kind of ostracism in which Argentina falls cyclically, at least industrially, as we have seen in this brief journey through the economic, political, social, and industrial history of Argentina.

Implementing one's own ideas, at least, in Argentina, as can be deduced, is very difficult due to the inheritance of intellectual dependence and the lack of capacity and resistance of the actors. TRIZ is one of those ideas, which is difficult to implement in university classrooms and in companies and industries. Surprisingly, the possibility of inserting something that has triumphed in so-called first-world countries is very much denied.

6.6 TRIZ in Argentina

Apparently, the first beginnings with TRIZ come from the research of the engineer Juan Carlos Nishiyama of the UTN FRGP in 2002. As of 2003 Carlos Requena, professor of UTN FRGP, joins the subject. By then, TRIZ materials were very few in Spanish in Argentina, more material was available in English. The bulk of the materials was widely available in the Russian language, inaccessible at that time for idiomatic reasons, and resources to make them accessible. In addition to this, this TRIZ issue was not officialized as a programmatic investigation in UTN FRGP, or anywhere else in Argentina, at least to our knowledge. However, these obstacles were not limiting the research activity. He was oriented to study USIT (Nakagawa 2004) of American origin and totally in English, much more accessible. He went deeper into USIT and understood some TRIZ by deduction from USIT.

The access to TRIZ was due to a fortuitous situation and we have widely taken advantage of it, since the third person to join the group, of only two members who no one believed about the usefulness of these issues, was Tatiana Zagorodnova, of Russian nationality and student of the Degree in Industrial Organization also from the UTN FRGP. She was discovered by pure chance in chemistry lab classes because of her accent and the need to translate written TRIZ materials from the Russian language. Thanks to her proficiency in Spanish and her native language, she helped us to know the TRIZ methodology from Russian authoritative sources. Many of them are from the website of the “Altshuller Foundation” (Altshuller 2003).

Since then, we have been dedicated to TRIZ and growing through its website translation and at the same time, as there was something translated into French, English, and German, it was decided to add them to what was already in Spanish, translations of the study and thus to be fully exploited by the Spanish-speaking interested public.

We have had direct contact with the Chemical Engineer Oscar Isoba, with whom we have shared materials. Unfortunately, this person passed away. We are dedicated to disseminating in other UTN regionals such as Regional Villa María in the province of Córdoba, Regional Paraná in the province of Entre Ríos, Regional Tucumán in the province of Tucumán, Regional Buenos Aires in CABA, Regional Delta in the province of Buenos Aires, etc., as well as the Faculty of Chemical Engineering of the National University of Mar del Plata in the city of Mar del Plata in Buenos Aires province. We have also disseminated in the UADE (Universidad Argentina de la Empresa) in CABA and in the UCA (Universidad Católica Argentina) in Puerto Madero, CABA, in which we already issue TRIZ topics.

We have knowledge of a few professionals who research or teach TRIZ. There are some advances in the subject, for example, something in INTI that resulted in a university graduate project by the engineer Otto Stier at FIUBA (Faculty of Engineering of the University of Buenos Aires) in CABA, which appears, among other topics TRIZ.

Inquiring into some programs of various universities, we have seen some TRIZ topics as part of the unit of some subjects. We have participated in specialized foreign conferences such as AMETRIZ. Also, in translation and participation of books on these topics such as USIT, HI, newsletters from USIT, all from Sickafus. We are in the translation of the TRIZ book by Isak Bukhman, a direct disciple of the creator of TRIZ, Genrich Altshuller. We have also translated from Russian to Spanish almost all Altshuller's work on the Russian page of the "Altshuller Foundation" (Altshuller 2003), holders of the rights of the creator of TRIZ.

So far, in Argentina we have held the "1st Argentine Congress of TRIZ. Creativity and Innovation applied to the development of new Products and Processes". In addition, we have held the "TRIZ Methodology Innovation Symposium" in 2019 between UCA and UTN FRGP.

Both in these mentioned above and other events, we have been able to count the presence of leading exponents on these issues of different nationalities such as Chile, Brazil, United States, Latvia, and Mexico.

We have knowledge of at least one Argentine master's thesis, in which TRIZ was used, the author is Mario Lozano is engineer of the UTN Villa Maria Cordoba Argentina (Lozano 2016). The Director of that work is Dr. Pedro David Cufré, and the Co-director is Dr. Edgardo Córdova López who belongs to the AMETRIZ (Mexican Association of TRIZ) steering committee. We ignore if there is another work like that.

It is worth mentioning recent work on TRIZ activities in the FRGP UTN. This work belongs to the School of Economics and Business of the National University of San Martin of Argentina with the Specialization in Technology and Innovation Management (Aja et al. 2019).

With this, we want to show that great efforts have been made by the authors and other collaborators who see the importance of these structured methodologies. Despite this, there is still a lot to do to introduce TRIZ, and derivatives, in Argentina. Some of the "critical mass" of professionals is just being created.

6.7 TRIZ Teaching in Argentine

In UTN Pacheco, the subject "Methodologies for the Development of Creativity in Engineering" is included in the Mechanical Engineering curricula. It is an annual elective subject.

The program presents unstructured methodologies such as Brainstorming, Synectic, Trial and Error, etc., but only as a simple presentation since there is abundant information and professionals on these issues. Our goal is to point out structured methodologies.

However, we teach the semi-structured methodology called Equivalent Transformational Thinking (by Kikuya Ichikawa), virtually unknown outside of Japan. In our experience, acquired since 2015, explaining and then practicing with students with this methodology was a very good experience before addressing structured methodologies (Kenworthy and Kielstra 2015). With this, students begin to appreciate:

- The importance of solving problems
- The importance of teamwork
- The importance of communication between teams.

Then we begin with the deep teaching of TRIZ. based on our experience, perhaps not much, we begin to derive the teaching of TRIZ towards TRIZICS that results in a more orderly reasoning that includes TRIZ as a subset among other subsets of non-TRIZ tools that allow the student to see for themselves the essential that For any problem, the first thing to do is identify the problem (definition of the problem), and in that TRIZICS allows students to do it using their non-TRIZ tools. In addition, the student can select the type of problem from only 4 types, basically: with unknown root cause, with known root cause, improvement, and development and, finally, failure prevention.

According to the selected type of problem, TRIZICS provides, in an unmistakable structure, a group of analytical tools, specific to each type of problem.

At this point, something difficult is achieved in TRIZ, which is: Define the specific problem(s).

Here, already stripped of psychological inertia, almost inevitable in non-structured or semi-structured methodologies, the student can apply the: Solutions Tools, through the specific and abstract modeling of the problem, and then apply the specific abstract solution model.

In this last stage, the application of the solution takes place and with it the abstraction way out. From TRIZ we go to SIT (Structured Inventive Thinking) and ASIT (Advanced Structured Inventive Thinking) at Horowitz of Tel Aviv University. This is briefly, as the importance will be given to the USIT. Also, from Sickafus we address HI (Heuristic Innovation).

The latter, we already find it difficult to achieve in the teaching of the mentioned course. The academic year, unfortunately, is not enough, added to the inexperience that the authors declare, since we do not have training in teaching models of these topics, since in the country it is practically impossible. If we rely on advice and programs on TRIZ, kindly provided by more experienced Mexican colleagues.

One of the ways that brought very good results regarding the communication of the students we have achieved, not only with the exhibition of the works among them but, making them participate in numerous engineering congresses where they presented their resolutions of technological problems of their own practical work of the course in paper format and oral presentations through audiovisual resources.

This accomplishes the three important steps mentioned above. Among other activities, we have made them participate as co-authors in the book the 40 Principles of Inventiveness and in another book under development called the 10 Additional Principles. We continue with this participatory policy in the draft of other books.

We have no other TRIZ references in the country. There may be some, but we don't find it in the international circuit nowadays. What may be in the national circuit is so far from this and something else that we have not glimpsed yet.

6.8 Conclusions

From Argentina's economic history, among the reasons why TRIZ is not implemented, we can appreciate the lack of interest in innovation as a deep topic, not as marketing to simply increase sales. In general, in Argentina, despite having a Ministry of Science, Technology, and Productive Innovation, an important government action, that culture has not yet been developed. This takes time and can be justified, perhaps by the hard-historical matrix established since colonial times with an agro-export model and subsequently protectionist from the governments regarding the manufacture of products, all of which, do not allow an advance, challenge, and competitiveness with foreign countries.

A great ignorance of structured methodologies by most professional technologists takes place in Argentina. That, not knowing these issues, will never appear in university classrooms, an ideal place for these and not only about engineering.

You can add to all this, fear and great rejection of the unknown. It is preferable to what is already installed and not to risk, as expressed with continuous improvement.

TRIZ, despite all of this, seems to be making its way in the fight against a whole idiosyncrasy thanks to the efforts of protagonists that are joining forces in the same direction. They are being achieved, at least in universities such as the UTN, UCA, and surely some other houses of high studies that we involuntarily ignore, student engineers, who at least graduate have been studying and implementing the TRIZ methodology by solving problems.

More and more awareness is raised that the engineer must solve problems, the one to do. There is still enough in the nebula how to do it. Knowing and applying TRIZ, according to the opinion of at least these authors, is the key.

In the words we have adopted, we want to express what is becoming more real and conscious for companies that want to overcome or survive: "Innovate or Die" (Mann 2009).

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Chapter 7
Technology Roadmapping and TRIZ: A Practical Approach for Inventive Problem-Solving and Product Innovation

Eusebio A. Bolaños-Ruiz

Abstract The application of the Technology Roadmap (TRM) methodology to manage the design process is an active research field. The TRM capacity to establish a map which unveils relevant relationships in time, available technology, and the market demands is an attractive resource to improve the innovation process in any organization. The intensification of the research effort revealed new paths for proposing more efficient innovation planning tools and techniques. The combination of these tools has as result in the improvement of innovation research efforts. In this chapter, the proposed solution to the TRM limitations to manage market information is to use an approach created to solve complex problems: The Theory of inventive problem solving (TRIZ), which has the capacity to produce valuable technological solutions. Also, TRIZ is an attractive resource to impel the innovation process and the data management. TRIZ, used as a secondary tool in the TRM process has the capacity to increase the TRM efficacy.

Keywords Technology roadmap · Design planning process · Inventive problem modeling · Physical and technical contradictions

7.1 Introduction

The benefits and advantages of the Technology Roadmap (TRM) as a tool to assist the products design planning process, attract the industrial and scientific community attention. Several important enterprises, governments, and investigation centers use TRM for their product and service development. Simultaneously, the application of TRM in different contexts has impelled its improvement and the incorporation of secondary tools to the TRM planning process. The incorporation of these tools in the TRM process revealed new research opportunities and drawbacks. Despite of their popularity as a primary design tool in the planning process of many organizations, TRM has several limitations. One of the most significant TRM problems lies on their

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capacity to obtain and manage information from the market (Kamama and Kondo 2007). This problem is partially solved. To deal with this problem, the organizations normally use secondary tools as brainstorming, lateral thinking, and other psychological approaches. However, technical, statistical, and scientific knowledge is rarely used in this stage of the TRM process.

Another significant problem of the TRM planning process is that it does not have any tool or approach to show the user what is the right technological development path or how to incorporate an existent technology into the design process. The decisions to deal with these situations are based on the experience and knowledge of an expert or a research team, instead of consulting databases and construct a formal data analysis based on the market demand (Kamama and Kondo 2007).

There is an approach that allows the solver to use a range of technical tools to solve inventive problems identifying technological evolution paths: The theory of inventive problem solving (TRIZ). This theory postulates three principal concepts to understand the innovation processes. The first of them sets than the problems and solutions repeat themselves in all industries and sciences. The second one explains that there are some evolution patterns that can explain the development of a technical system. The last one establishes that the innovations process must use scientific knowledge to solve their intrinsic conflicts (Ekmekci and Koksal 2015).

TRIZ offers a range of tools that allows the solver to manage the data available in the market using the TRIZ patterns of evolution as data classifiers in conjunction with a data management software. Also, TRIZ enables the user to recognize the evolutions patters which provide new solving paths in the innovation process. Consequently, the combination of TRM and TRIZ offers to a solver the capacity to planning the design process, to integrate information from the market, and to offer a wide perspective that aims to facilitate decision-making.

This chapter proposes a framework, which combines the technology roadmapping with the process of TRIZ for solving inventive problems. This Chapter has four sections. The first section explores the TRM opportunities for improvement. The second section describes the TRIZ approach. The third section offers a methodology to develop inventive problem and depicts a case study. The last section discusses the advantage and limitations of the combined approach.

7.2 Technology Roadmapping: Opportunities and Advantages

Technology Roadmapping is a technique extensively used in public and private instances to support strategic and long-range planning. This tool provides the user structured and graphical means to explore and communicate the relationship between markets, products, and technologies over time (Phaal et al. 2004).

TRM has two perspectives, the first is the company perspective: A roadmap that allows technology developments to be integrated in a business planning, and the impact of new market developments. The second is a multiorganizational perspective: A roadmap that seeks to capture the environmental landscape for a group of stakeholders in an application area (Phaal et al. 2004).

The reasons behind the interest that TRM unveils repose on their advantages and among the most relevant are:

1. TRM allows the user to explore and communicate the dynamic linkages between technological resources, organizational objectives, and the changing environment. A TRM can develop not only products but services, analyzing the market behavior.
2. The TRM can be customized according to the different business aims including product planning, exploration of new opportunities, resource allocation and management, and improved business strategy and planning.
3. TRM can be combined with secondary tools to improve their data management and their validity.

Like any other innovation management tools, TRM has several limitations (Phaal et al. 2004).

1. TRM is not a "black box" methodology, each application is a learning experience, and that flexible approach is required and adapted to the circumstances being considered.
2. Many of the benefits of roadmapping are derived from the roadmapping process, rather than the roadmap itself. The process brings together people or data from different parts of the business, providing an opportunity for sharing information and new ideas.
3. The graphical form of the roadmap is a powerful communication mechanism. It can present information in highly synthesized and condensed form.
4. Software alone cannot deliver good roadmaps. It needs to be integrated with the human aspects of roadmapping.
5. The combination of roadmapping with strategic planning, information retrieval, data mining, S&T evaluation, and organizational performance metric, must be addressed well in advance of the implementation of a roadmapping process.

In the context of this chapter three drawbacks are particularly relevant:

1. The need for a tool to analyze and classify technology. A patent analysis based on TRIZ trends can show the solver which are the market tendencies and the market segment opportunities.
2. The necessity to manage the market information using a technical approach. Nowadays, the market preferences are analyzed by an expert group, normally using trial and error solving approaches like design thinking, brainstorming, or Six thinking hats. Despite the usefulness of these methods, TRIZ offers several tools based on technical experiments and patent analysis.
3. To explore the possibility to solve conflicts inside the planning process. TRIZ offers the tools for modeling and solving inventive problems formulated as contradictions, functions, or evolution patterns. The integration of TRIZ into the TRM

modeling has two stages: (1) It is necessary to identify the most relevant evolution path to a system, product, or process. (2) Formulate the problems to move the system forward in this direction and apply the TRIZ tools (contradiction matrix, 76 standard solutions, to mention some of the most frequently used TRIZ tools).

The central hypothesis of this chapter states that a combined use between TRIZ tools with TRM can provide a better TRM performance and surmount these limitations. The next section describes the TRIZ approach as part of the logic to demonstrate the feasibility of a synergy between both approaches.

7.3 Theory of Inventive Problem Solving

The TRIZ model was developed by Altshuller in the Soviet Union in the forties (Rantanen and Domb 2007). The TRIZ model stands out for its response to problem solving, the need to create new systems, and the selection of solutions within different contexts.

The TRIZ model is used around the world, being employed mainly by leading industrial nations. The creator of this model lived almost all his life in Baku, excepting the period 1950–1054, which was confined in different Soviet prisons. Altshuller found that a variety of different systems and technologies had similar patterns of evolution (Rantanen and Domb 2007).

Under the author's assumption, an inventor could learn about these patterns of evolution and with this knowledge develop new technologies, avoiding several errors born of experimentation. This way of thinking was not accepted by Stalin's government, so his arrest was imminent.

After Stalin's death, Altshuller was released from prison and for the next 30 years, his model was taught at universities, military schools, high schools, and independent schools focused on the TRIZ model. The model is still in force and has been instrumental in the development of other tools.

TRIZ has been defined in many ways (Zakharov 2008):

1. A theory, which is established on objective trends of technology evolution. TRIZ describes the process of new technology creation by mankind.
2. A science, which studies evolution of technological systems, and proposes a methodology for the synthesis, development, and forecasts of such systems.
3. A set of concepts. These concepts do not create the whole unity, in contrast to many applied methodologies and theories. The knowledges and concepts, which are included in TRIZ, may be considered art.

The foundations of the Theory of Inventive Problem Solving (TRIZ) are a set of technical and scientific knowledge. The main difference between TRIZ and other solving tools is the transversal problem-solving knowledge methodology.

The TRIZ Theory establishes that the process of innovation is not random but is governed by certain rules that can be studied to extract some patterns with a transversal application. Originally, the creator of the TRIZ theory, Genrich Altshuller conducted a study on many patents and concluded that the solutions applied in different areas of engineering were repeated in multiple fields. In many cases, solutions between different systems were years away, caused by the lack of communication between systems. The problem is then the diffusion of ideas between different areas of knowledge. Consequently, TRIZ proposes to establish a system that allows to interact the existing solutions with the problems (Rantanen and Domb 2007).

TRIZ states that the solutions proposed in a particular domain can be adapted to other fields. To accomplish this goal, it was necessary to propose a generic and reusable structure to model and solve problems. The concept of contradiction covered this purpose. A contradiction gets revealed when the system, a component, or a functional parameter in the system demands a certain state to obtain a useful condition, nevertheless, its presence produces an undesirable effect in another useful part of the system, or it is necessary the opposite state to guarantee another useful output in the system. There are two contradiction classes: physical and technical. Each one has its specific solving strategy and tool. A physical contradiction is faced via the separation principles. Technical contradictions call for the contradiction matrix, which connects one problem with a set of solving principles validated in other technical domains and represented as abstractions (Altshuller 1984). The basic rational purpose for solving an inventive problem with TRIZ is to find the contradictions in the system and solve them, instead of looking for a trade-off solution.

Although the TRIZ methodology in its traditional form has worked for problem-solving, the application in different domains revealed some drawbacks: (1) TRIZ cannot deal with simultaneous conflicts; (2) It proposes different tools according to the situation to solve, which increases the adoption effort in the user; (3) It needs a collective approach for problem-solving (Delgado-Maciel et al. 2007). The software assistance is one of the most successful paths for improvement and increasing the adoption of this technology. This tendency produced the concept of Computer-assisted innovation, which in collaboration with the technological roadmap has the potential to achieve better results.

7.3.1 TRIZ Tools

TRIZ has a range of tools to assist the problem-solving process. In this chapter, one of them is crucial: The Trends of Evolution. This tool is based on a vast patent analysis and the statistical information derived from this effort. Due to its importance, the next points briefly describe how to apply this tool.

7.3.2 TRIZ Evolution Trends and Patterns

Perhaps the most promising TRIZ tools are the trends and patterns of evolution. The idea that technological systems tend to go forward in a way analogous to that of biological systems has been supporting the research of the evolution of several products (Leon 2006). These trends show the most used tendencies along the global product innovation process. TRIZ theory is substantiated by the idea than a solution used in an industry could be used in another problem with similar characteristics. This is the logic of several TRIZ tools. For instance, the contradiction matrix states that if the same technical contradiction is useful to model two problems, then the validated solution in one of them could be transferred to the second problem.

The TRIZ evolutions patterns are (Leon 2006):

1. Technology follows a life cycle of birth, growth, maturity, and decline.
2. Increasing Ideality.
3. Uneven development of subsystems resulting in contradictions.
4. Increasing dynamism and controllability.
5. Increasing complexity, followed by simplicity through integration.
6. Matching and mismatching of parts.
7. Transition from macrosystems to microsystems using energy fields to achieve better performance or control.
8. Decreasing human involvement with increasing automation.

Every one of these patterns shows the evolution tendencies in several products, even without an apparent relation and industries. The trends of evolution are useful to evaluate the next steps in the evolution of products, processes, or technologies and therefore, to increase the possibilities to perform better in the market (Leon 2006). Usually, an invention not only belongs to only one trend but there is also an interaction among the patterns, for instance, the patterns of matching and mismatching elements can help the innovator determine a general pathway of focus. The system might evolve in a way that connects functionally different but co-dependent elements rather than in a way that taps into the progression of matching elements (Slocum 2010).

7.3.3 TRIZ Advantages and Limitations

The TRIZ advantages over other try-and-failure approaches are:

1. TRIZ facilitates the connection between the problem requirements with a range of scientific effects that can produce the desired goal, therefore scientific knowledge is a crucial element in the solving process (Savransky 2000).
2. The TRIZ-solving process creates a synergy where the individual psychology patterns become more flexible while simultaneously enables the knowledge creation via the analogical thinking (Fey and Rivin 2005).

3. The TRIZ tools create a context where the frontiers among domains become fuzzy. Thus, the successful solutions available in an area could then be transferred and reused in a different problem (Altshuller 1984).

Like any other approach for problem-solving, TRIZ has several limitations (Delgado-Maciel et al. 2007):

1. The dependency on the user's experience to determine the right problem to solve and the subjective selection of the plausible solving path.
2. A considerable abstraction effort is to apply the TRIZ tools in the service design field.
3. Collaboration and collective intelligence are necessary to solve inventive problems.
4. The appropriation of the theory is a complex task. The exigencies to assimilate all the TRIZ tools is one of the most explored drawbacks.
5. The necessity to solve simultaneous conflicts. The formulation of an inventive problem produces, in many cases, a situation where the solver recognizes the existence of more than one crucial conflict.
6. The lack of a tool to dynamically model the essential relations within a problem. The internal and external environment of a system is changing continually.

7.4 Computer Aided Innovation

In this chapter, the purpose of combining the TRM and TRIZ is to propose a planning process to identify the improvement paths of a product, process, or service. However, the use of combined approaches between TRM and other design tools is not a new idea. TRM usually asks for a secondary data market tool, which is used to collect, measure, and manage the market information and to distinguish the consumer preferences. Different research efforts have used try-and-failure approaches to define the market trends and a strategy to add new characteristics to products or services without much success. The next point briefly explores these works.

7.4.1 Related Work

Daim et al. Apply a TRM to the Bonneville Power Administration (BPA) in Oregon, United States with the propose to create an innovation plan to improve their energy activities and objectives. In this TRM, BPA uses four investigation groups to develop a new technology based on the company objectives. The secondary tools used in this investigation were brainstorming, QFD and a consulting group (2014).

Allan et al. propose a TRM to identify the technological needs in the semiconductor industry. The International Technology Roadmap for Semiconductors

(I.T.R.S.) collects information from five geographical regions and manage it to recognize the market needs and the evolution trends (2002).

Lamb et al. use a TRM to reduce the production cost on the Oregon Wood Innovation Center. The wood pellet fabrication process is investigated to create new alternatives in the wood pellet uses. The secondary tools used in this TRM are the FODA matrix, QFD, and a market study (2012).

Amer and Daim Apply a TRM in the renewable energy sector on the United States. The objective of this project is to create national and international roadmaps and identify the renewable energy trends. The secondary tools used on this investigation were FODA matrix, Delphi method, PEST (Economic, Social, and Technological) analysis, and QFD (2010).

Cho et al. present a TRM to the Korean government to stablish a national planning to develop a technology national plan from 2000 to 2012 in the 19 principal South Korean industries. The secondary tools used on this investigation were FODA matrix, Benchmarking, investigation seminaries, and expert group (2016).

McDowall design a TRM to the UCL (University College London) energy institute to popularize the hydrogen energy in the United States. According to this investigation, there were 15 TRM investigations related to hydrogen energy. The author rates their quality and their utility. The secondary tools used on this investigation were a questionnaire and a database (2012).

Lee et al. propose a TRM to improve an “Intelligent city” in South Korea. The Korean technology ministry aims to improve the space was the transport, the communication, the social, and intellectual capital insure the natural, social, and intellectual resource management. The secondary tools used on this TRM were Delphi model, QFD, and GRID (2013).

Abbasi et al. propose a TRM to create a TRM model to the creative industries like videogame, arts, and design industries. The Surrey Business School uses the Delphi method, data mining, and a set of different scales to manage the information and as secondary tools (2017).

Daim et al. Propose a TRM to create the new hybrid PC’s next generations analyzing the technologies over time. In this didactic exercise, the solvers use macroeconomic studies, literature revisions, questionnaires, and cost analysis as secondary tools to manage the market information (2014).

Daim et al. Propose a TRM to create a hybrid car and to plan their future improvements across time. Tesla Motors is a company dedicated to design and distribution of electric cars in the United States. The secondary tools used in this TRM were the QFD matrix, and STEEP analysis and a decision tree (2014).

TRM does not have a wide accepted methodology, every user can decide the graphical form, the process to collect and manage the market and technology information. However, there are six steps usually observed in any TRM process. A solver can use these steps to build a TRM (Daim et al. 2014).

- S.1Identifying the needs and drivers
- S.2 Identifying products or services to meet the needs and drivers
- S.3 Identifying technologies to support the products or services

Table 7.1 TRM projects and their construction process behavior

Organization	S.1	S2	S3	S4	S5	S6
Bonneville power administration	√	√	√	√	Ø	Ø
TRM for semiconductors	√	Ø	√	√	√	√
Oregon wood innovation center	√	√	√	√	Ø	Ø
Renewable energy sector	√	√	√	√	Ø	Ø
South Korea R&D planning	√	√	√	√	√	√
Hydrogen energy	√	√	√	√	Ø	Ø
Korea city development	√	√	√	√	Ø	Ø
Cultural and creative industries	√	√	√	√	√	Ø
Next generation PC	√	√	√	√	√	√
Tesla motors	√	√	√	√	√	√

- S.4 Establishing the linkages among steps one to three
- S.5 Developing plans to acquire or develop the technologies
- S.6 Assigning resources to accomplish the plans for acquisition and development.

Related work shows that the standard methodology observed in different TRM processes is the basic process. However, only a few of works propose a plan to acquire or develop the suggested technologies or assign some resources to accomplish the acquisition and development plans (Table 7.1).

The secondary tools more frequently employed to manage the information in the related work were registered in Table 7.2. According to the frequency of use identified in the related work, there are 17 secondary tools used to obtain and manage information. Some of them are psychological approaches, but others are statistical and technical tools to manage information.

A. Brainstorming	J. Benchmarking
B. Q.F.D	K. project briefcase
C. Expert consult	L. GRID
D. literature analysis	M. Data Mining
E. SWOT	N. Questionnaires
F. Delphi	O. STEEP
G. Risk Analysis	P. decision tree
H. Patent analysis	Q. Comparation Lists
I. PEST	

It is interesting to notice that only one TRM uses a statistical approach as patent analysis or data mining to observe the market behavior and the innovation tendencies. Despite the know-how of an expert group, it is important to use the data available in the market to define the market demands.

Table 7.2 Secondary tools and their popularity in the studied related work

Organization	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Bonneville power administration	√	√	√	Ø	Ø	Ø	√	Ø	Ø	Ø	√	Ø	Ø	Ø	Ø	Ø	Ø
T.R.M. for semiconductors	Ø	Ø	√	√	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	√
Oregon wood innovation center	Ø	√	Ø	√	√	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	√
Renewable energy sector	Ø	√	√	Ø	√	√	√	√	√	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
South Korea R&D planning	Ø	√	Ø	Ø	Ø	Ø	Ø	Ø	Ø	√	√	Ø	Ø	Ø	Ø	Ø	Ø
Hydrogen energy	Ø	√	Ø	Ø	Ø	√	Ø	Ø	Ø	Ø	Ø	√	Ø	Ø	Ø	Ø	Ø
Korea city development	Ø	Ø	Ø	Ø	Ø	√	Ø	Ø	Ø	Ø	Ø	√	√	Ø	Ø	Ø	√
Cultural and creative industries	Ø	Ø	Ø	√	Ø	Ø	√	Ø	Ø	Ø	Ø	Ø	Ø	√	Ø	Ø	√
Next generation PC	Ø	Ø	Ø	√	Ø	Ø	√	Ø	Ø	Ø	Ø	Ø	Ø	√	Ø	Ø	Ø
Tesla motors	Ø	√	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	√	√	Ø

Tool's popularity Ranking:

1. Comparation lists
2. QFD
3. Expert consult
4. Literature analysis
5. Risk Analysis
6. Delphi
7. SWOT
8. Project briefcase
9. G.R.I.D
10. Questionnaires
11. Brainstorming
12. Patent analysis
13. P.E.S.T
14. Benchmarking
15. Data Mining
16. STEEP
17. Decision tree

Nowadays, TRIZ is not a popular approach to manage and classify information and neither is used on the decision-making process. The TRM users normally employ try-and-error approaches like Comparation list, a QFD Matrix or an expert consult to define the market demands and the technology trends. TRIZ is not a popular tool to satisfy the management needs of the TRM process.

The TRIZ tools can be a useful option to manage and classify information. Also, it can be used to incentive the solvers creativity and to obtain a better market perspective. The follow methodological approach is an TRM+TRIZ integration, created to get and manage the information to plan the next innovation design steps in a specific product.

7.4.2 Methodological Approach

This section describes the simplest process to connect the technology roadmap with the theory of inventive problem-solving. The methodology has four stages. These stages are the simplest strategy to combine TRM and TRIZ. Each stage uses aims to overcome the limits identified in the state-of-the-art.

This approach is based on the industry's tendency to follow the basic TRM structure, in this specific case, step 6 of the structure (Daim et al. 2014) is not considered because the TRIZ is integrated into the TRM process inside the steps 1, 4 and 5. In future approaches, use TRIZ to manage plans to develop the selected technology is a possibility.

7.4.3 TRM+TRIZ Approach

Step 1: Market context analysis

- Identify the competitors and their behavior.
- Identify the user's market conditions with the competitors.
- Compare the user's enterprise economic conditions with the competitors.
- Compare the user's products with the competitors.

Step 2: Demand analysis and market tendencies with TRIZ

- Make a patent analysis for similar products
- Identify the market preferences
- Identify the technological tendencies
- Classify the data using the eight patterns of evolution
- Propose a project portfolio using the patent data analysis.

Step 3: TRM formulation

- Stablish a timeline showing the existent technologies in the market
- Use de statistic patterns of evolution analysis to predict the follow innovations
- Use the contradiction matrix to integrate the available technology and the market demands and solve the intrinsic problems of the design process.

7.5 Case Study: Product Innovation Using TRM+TRIZ

The objective of this TRM+TRIZ application is to design a TRM for a start-up in the private sector in Mexico. The company dedicates to the production and adaptation of packaging and straws using alternative biodegradable materials. In this case, the company wants to conceive a TRM to stablish the evolutions paths to design a biodegradable straw.

Table 7.3 Market's competitors and product description

N	Company	Product description	Country
1	World centric	Viable material for the compost	U.S.A
2	Aardvark	Paper straws	U.S.A
3	Ecoproducts	Viable material for the compost	U.S.A
4	Bamboorganic	Natural cellulose coated with resins	Mexico
5	Ecoshell	Natural cellulose coated with resins	Mexico
6	Ecoalternativas	Biodegradable fibers	Mexico
7	Bioproducts	Cornstarch	Mexico
8	Smartgreen	Oxo biodegradable—bagasse	Mexico
9	Greenworld	Oxo biodegradable—bagasse	Mexico
10	Popotes de Bambú	Made with bamboo washable wood	Mexico
11	Kalalt (User)	Oxo biodegradable—bagasse	Mexico

Step 1: Market context analysis

In this step, the user identifies the market competitors and their behavior. In this case the main producers have been identified at a regional level. Several among these companies are from the United States of America but they share the Mexican market. Table 7.3 summarizes the principal competitors in the market.

The market study shows what are the more significant production process tendencies nowadays. The most successful business uses a process to create biodegradable straws that are viable for compost use. Another company business uses a similar process based on natural cellulose coated with resins, the use of bagasse or cornstarch as raw material. It is also remarkable that one company produces reusable straws made with bamboo. The next step explores what are the demand for this kind of straws.

Step 2: Demand analysis and market tendencies with TRIZ

The objective in this step is to analyze the competition in the market. A patent search in worldwide databases is a valuable resource to identify competitors and to obtain and manage information. In this step, the data was obtained from the "Espacenet" database (EPO 2017) and manage with the RapidMiner® software. The search uses the Cooperative Patent Classification (CPC) codes. This decision aims to facilitate the search in three patent databases: the USA patent database (USPTO), the European Patent Office (EPO), and the World Intellectual Property Organization (WIPO).

The patent codes to search in the database were: A47G21 (Drinking straws), B05C5 (Apparatus for applying liquids or other fluent materials to surfaces, in general), and B32B (Layered products having a general shape other than plane). The analysis considers 200 patent titles published from 1999 to 2017. Altshuller (1984) proposes the methodology to manage the information from patents. The patents were classified into eight categories, separating them by keywords. Each one of these categories is one of the eight standard evolution TRIZ paths.

The keywords were selected according to the characteristically behaviors of each evolution trend. In this case, the RapidMiner software classifies the patents according to the keywords in Table 7.4. The RapidMiner software also tokenizes the keywords to find related words in the patent titles. In this specific case study, the software only classifies one patent to one trend, but there are other kinds of software which can classify the patents in multiple trends (Yoon and Kim 2011).

The following information shows the industry innovation tendencies. This tendency is quite remarkable, but only with this kind of study it is possible to confirm the behavior with a statistical analysis. From 200 patents, 69 were not related to drinking straws or similar. The most popular tendency is the trend number 6, "matching and mismatching of parts" followed closely by trend number 2, "Increasing ideality" (Table 7.5).

In the biodegradable utensils industry, there is strong tendency to propose new ways to reduce the ecological impact. The more frequent strategy is to substitute typical raw materials and employing new materials and more efficient production

Table 7.4 Evolution trends and their keywords

N	Evolution trend	Key words
1	Technology follows a life cycle of birth, growth, maturity, and decline	Cost
2	Increasing ideality	Biodegradable, ecological
3	Uneven development of subsystems resulting in contradictions	Magnetic, intelligent
4	Increasing dynamism and controllability	Lazy, instant, spill
5	Increasing complexity, followed by simplicity through integration	Fluid, immobile, pore
6	Matching and mismatching of parts	Direct, dual, flexible, double
7	Transition from macrosystems to microsystems using energy fields to achieve better performance or control	Automatic
8	Decreasing human involvement with increasing automation	Automatic

Table 7.5 Evolution trends patents total

Evolution trend	Patent total
Patent not related	69
Trend 1	2
Trend 2	39
Trend 3	15
Trend 4	10
Trend 5	13
Trend 6	40
Trend 7	7
Trend 8	5

processes. This tendency is especially evident in children's design products. The tendency is to create drinking straws with creative designs, to avoid the spillover or to help the users to drink easily (Graph 7.1).

The average interval between new patents into each trend varies considerably (see Table 7.6). For instance, trend two has a mean time between patents every 13 days, and there is a new patent every 11 days in trend six. This information is useful to the solver because it can help to plan the product release time. In this case study, the average time is employed to manage the time axis in the TRM. The trend analysis also uncovers information about the market. In other words, the team working in the TRM could choose between dedicating their R&D efforts to follow the stronger market tendency, to focus their attention to preserve the market segment or finally, to explore a new market. In this specific case study, the team aims to develop a new packing and utensils employing degradable materials (Table 7.7).

Graph 7.1 Patent total

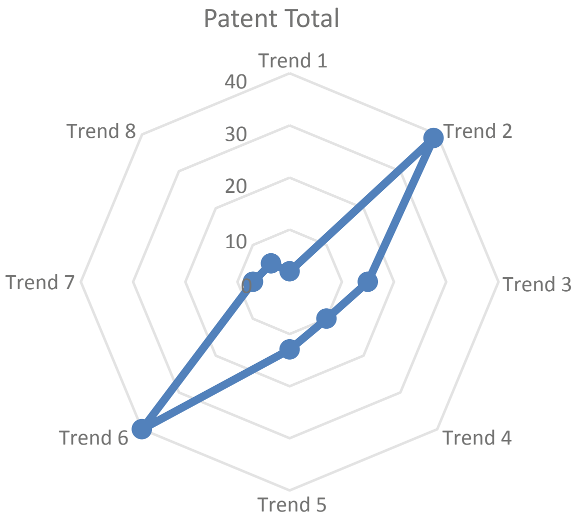
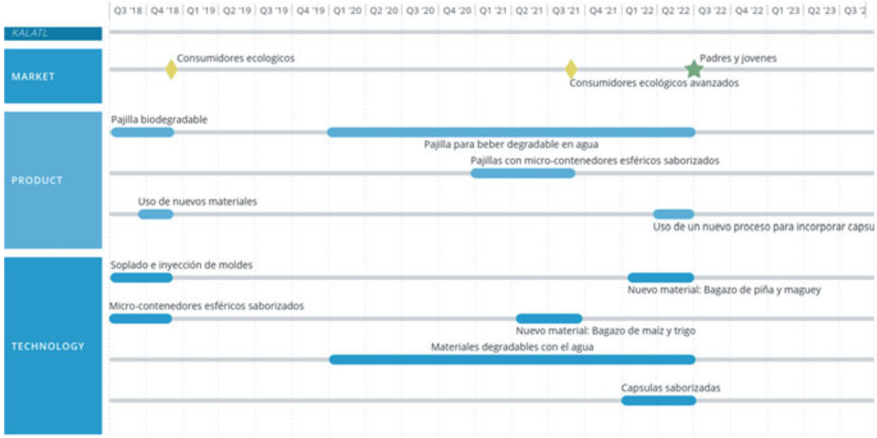


Table 7.6 Average patent publication time per trend

Evolution trend	Average time (Days)
Trend 1	55
Trend 2	13
Trend 3	35
Trend 4	48
Trend 5	27
Trend 6	11
Trend 7	45
Trend 8	15

Table 7.7 Technology roadmap



To create a new technology planning proposal, the company has chosen to use trends 1, 2, and 6 to develop a medium-term TRM, in this specific case for 5 years.

Step 3: Formulation of the TRM

The following map shows the research and development planning for Kalatl. The selected technologies were designated by the TRIZ trend approach. Using a trend mix of 1, 2 and 6, and a financial capacity analysis, a TRM is created for the next five years. The objective of this TRM is to improve the real production process, the raw material, integrate new features, and meet specific needs.

Description of the TRM planning:

Market

The row "Market" shows the 3 target markets considered within the time of the TRM. Due to the limited budget of the company, it seeks to access a general market of relatively low barriers to entry compared to long-term objectives. The markets to which access is sought are the following:

Ecological consumers—Target: December 2018

Description: Ecological consumers are young men or women or adults from 12 years of age and older, whose consumption preferences are inclined to seek options for everyday products. In the case of Kalatl, it seeks to sell organic products, whose price is relatively higher than their existing counterparts in the market. Finding consumers whose preferences focus on obtaining greater satisfaction with environmental care and responsible consumption over price is fundamental.

Advanced organic consumers—Target: December 2022

Description: The advanced ecological consumers are young men or women or adults of 12 years and older, these consumers are willing to consume products whose environmental footprint and practicality are fundamental elements, even at a high price. The aim of Kalatl is to incorporate biodegradable materials into everyday products, using economies of scale to reduce costs in the long term. However, the business structure indicates that in the short term, it is necessary to have consumers who can pay a higher price than the average.

Parents and youth—Goal: December 2023

Description: Parents and young people are a market of men and women from 12 years old and up, who are interested in having interesting objects, whose entertainment value lies in the curiosity of the object. The object to sell is interesting for infants from 0 to 12 years, the final consumers of the product are children, however, it is the parents and young people who acquire the product.

The selected markets have specific goals, due to the time of development, acquisition, and implementation of processes and technology. The TRM shows the relationship between markets, products, and technology over time.

Product

The row "Product" shows the products to be developed over time. These products are directed to the 3 markets indicated in the "market" column. The selection, development, and acquisition were selected by the separation of words made through patent mining with RapidMiner. The tendencies demonstrated by means of market behaviors show that there are niches for the development and construction of the following prototypes. Development times respond to budgets, development, and acquisition of technology and experimentation, as well as expected market and technology changes.

- **Biodegradable straw**: The product is an elongated cylinder whose purpose is to drink liquids by means of the user's suction action. The composition of this product is made with a material composed of biodegradable bagasse residues. Development or acquisition time: July 2018–December 2018.
- **Use of new materials**: The use of new materials within the process reduces production costs. Development or acquisition time: September 2018–December 2018
- **Drinking straw degradable in water**: This straw model has the peculiarity of beginning its degradation process when in contact with water. Development or acquisition time: December 2019–July 2022
- **Straw with spherical micro-containers**: This straw model, focused on the children's market, will have spherical containers, which release flavorings for liquids drunk through the straw. Development or acquisition time: December 2020–September 2021
- **Use of a new process to incorporate capsules that release flavorings**: The process to include the capsules that release flavorings inside the cylindrical

containers is an element to develop within the production process Development or acquisition time: March 2022–July 2022

7.6 Discussion

As we can see, TRM+TRIZ is an alternative approach that is effective to analyze the market trends through the analysis of patents. The information enables a short, medium, and long-term technological planning. Despite their usefulness, the planning process has some advantages and limitations.

7.6.1 Advantages of TRM+TRIZ Over TRM

1. TRM does not propose a specific tool to obtain and classify information. Consequently, users must rely on their experience to define the market trends. TRM+TRIZ allows to differentiate between the market trends by providing a set of trends of evolution, which have well-defined characteristics. By analyzing the innovation trends in a period, it is possible to observe the more feasible paths and then to propose a product development strategy.
2. TRM does not provide any tool to model and solve the problems that undoubtedly will emerge in the transformation of a product, process, or technology. The integration of the TRIZ tool provides then a framework to deal with the problems that will arise. The use of the TRIZ basic concepts such as ideality, technical contradictions, and trends of evolution offers a solving strategy already evaluated and tested in several domains (Ekmekci and Koksal 2015).
3. The patent research reveals the average time between new patents, which is evidence about the rate of the new product development in a particular product. This information is useful to estimate a correlation factor with the introduction of a new product to the market.

7.6.2 Limitations of TRM+TRIZ

1. TRM+TRIZ requires the assistance of a specialized data manager to analyze the large data set obtained from the patent analysis, depending on the degree of computer skills and statistics, the better the result obtained by the user on the analysis of trends. An experienced user can use more complex software, generating better ways to identify the characteristics of the analyzed patents.
2. TRM+TRIZ is not a method to produce "ready-to-use" solutions. In fact, the user needs to follow a brief training to the TRIZ tools, a situation that involves a change in the way of seeing problems. Hence, the capacity to propose new concepts and paths for transforming a product, process, or technology depends

on the creativity of the users and their ability to adapt the TRIZ tools in a particular context.

3. TRM+TRIZ depends on the existence of patents, and in the case of a newly created markets, there is not enough information, and the solver needs to explore the trends of evolution only relying on their experience. The service domain also is a challenge. Services are not suitable candidates for patent analysis, due to the little information available in the market.

7.7 Conclusion and Future Work

The purpose of this chapter is to explore the feasibility to combine the Theory of Inventive Problem Solving with the Technology Roadmapping based on their complementarity. The analysis of the TRM process revealed the necessity of a technical approach to obtain and manage information to define the market tendencies in a technology sector.

The use of the TRIZ trends of evolution allows the user to create the conditions to obtain and classify information and to propose an innovation strategy. The synergy between these two approaches is then feasible possible, which indicates the conception of a new problem-solving process where the advantages of both approaches are deployed systematically while their intrinsic limitation is surmounted.

Any effort in this direction is future work. Nonetheless, the researchers consider next points as a priority:

- A better recollection and analysis patent system. The tokenize process used in the RapidMiner software is efficient. However, it is necessary to identify more effective technologies to propose a more useful classification process. The use of ontologies, or other management knowledge techniques is a promising field.
- To propose a mechanism to reuse the strategies deployed in a TRM. According to TRIZ, there are technological patterns that are repeatable and transversal to different domains. From this point of view, a TRM should also have this capacity. More research is necessary to follow this direction.
- The simplification of the TRM+TRIZ approach with the goal to facilitate the adoption and application in different domains, specifically in the service and process domains.

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Chapter 8
TRIZ as a Strategy for Improvement of Process Control in the Wood Industry

Jhonattan Trejo Franco, Henrique Kozlowiski Buzatto, and Marco Aurélio de Carvalho

Abstract In wood machining, achieving the best product quality and reducing the factors that can negatively influence productivity are important objectives. To achieve this, the professionals involved must use all the available. Is it possible to use systematized creativity to solve typical problems in machining processes? The Theory of Inventive Problem Solving (TRIZ) is a powerful approach with untapped potential as a support tool in production systems in the timber industry. This chapter presents a conceptual proposal for solving two problems associated with cutting wood with circular saws. The methods used were the Innovation Situation Questionnaire (ISQ), the Interactions Analysis and the Inventive Standards proposed by Altshuller as a classic TRIZ tool. For the problem of identification of wear of the saws, it was recommended to use the field of easy measurement (power consumption) associated with a difficult measurement parameter (wear of the cutting tool in operation). For the heating problem of the tool cutting, it was suggested to incorporate a new field that neutralizes the damaging effect; this is a cooling field using compressed air jet in the cutting disks. In this paper, the application of the method is described step-by-step, as well as the inspiration for the proposals and the recommended applications.

Keywords Theory of inventive problem solving (TRIZ) · Wood sawing · Wear of saws · Heating of saws

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8.1 Introduction

8.1.1 Timber Sawmill

In the wood industries, quality management begins with the handling of the raw material, its storage, its classification and its processing or transformation into a finished product. The cutting tools are one of the main sawmill inputs that have a high impact on its productivity and the quality of the sawn wood since they are used to cut the raw material and transform it into the diversity of products required (Trejo et al. 2021). The main parameters that cause greater influence on the income of the timber industries and which, in turn, are controllable by the production team are the quality of the products, the yield of the raw material and the productivity of the lines. At present, trade and the high global demands for high added value forest products demand more and more satisfactory products, which implies high quality, as well as competitive volumes and delivery times, that is, more volume and in less time.

In wood cutting, five main objectives are sought, which can be summarized in (JUNAC 1989): Obtaining surface quality and accuracy of cuts, seeking efficiency in operation, control of tool wear, reduction of energy consumption and reduction of losses of raw material. The surface quality is especially important for industries, as it will determine the need for additional processing and/or reclassification to their possible end uses (Ghosh et al. 2015).

8.1.2 Circular Saws as Cutting Tools in Sawmills

The circular saws in the cut should be able to withstand the demands during the process, without losing its efficiency. The circular saws are formed by a circular metal body toothed at its periphery, which is responsible for cutting the wood longitudinally or transversely by rotating the cutting tool (Fig. 8.1).

To rotate, a circular saw must be under a centripetal force, directed toward its axis. This force has a non-constant behavior along the radio of the tool since its modulus is inversely proportional to it. Because of the non-constant modulus of the centripetal force, the related stresses on the tool are not uniform; they are stronger approaching the edge of the saw, and weaker at the proximity of its axis. After some time of usage, the dropping of the modulus of the centripetal force toward the edge of the tool leaves a footprint: A dimensional expansion towards the periphery of the saw, which eventually will become exceptionally large compared to its central part. The cutting force increases when the saw is worn, and the cutting temperature increases with increasing cutting force. The efforts that cause deformations in the disk also increase with the wear of the saw and add an important factor, which is the increase of the temperature, which causes the steel dilation and favors the deformations in the saw (Ninin 1986).

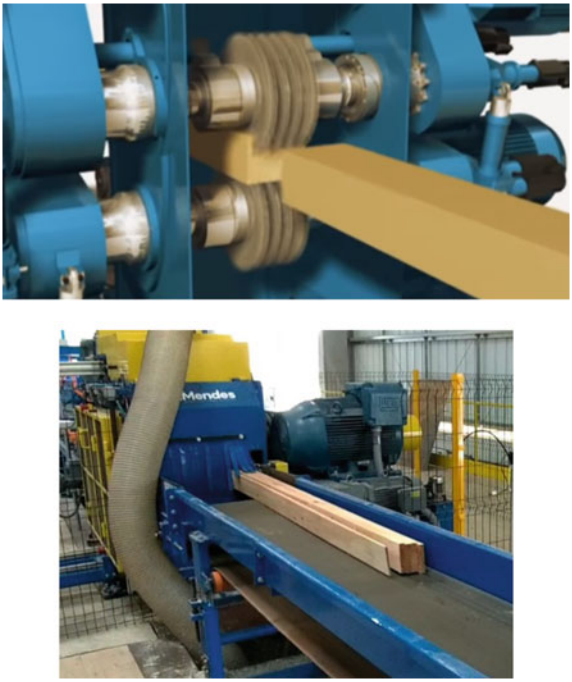

Fig. 8.1 Circular saws and wood block in the sawmill. Courtesy of USNR (sd). Söderhamn Eriksson (2018) and courtesy of Todesmade Indústria de Madeiras e Artefatos Ltda and Mendes Maquinas

The expansion around the periphery due to an uneven centripetal force; the mechanical impact of the tool with the logs and the related thermic events breaks the relation cumference $= \pi \times$ Diameter, leaving the saw deformed, with an eight-like shape, without the ability to oppose lateral resistance, this makes during the cut when describing the circumference, obtain a curved and serpentine line, longer than the linear $X - Y$ in the cutting direction (Fig. 8.2a). This is known as a loss of tension in the cutting disks.

As a consequence of the use of tension-less saws, sawn lumber is produced with significant dimensional variations in thickness and very low surface quality, characterized by surfaces scratched by the oscillation of the disk in the wood during its cutting trajectory (Fig. 8.2b); causing cutting marks on the wood, higher cutting

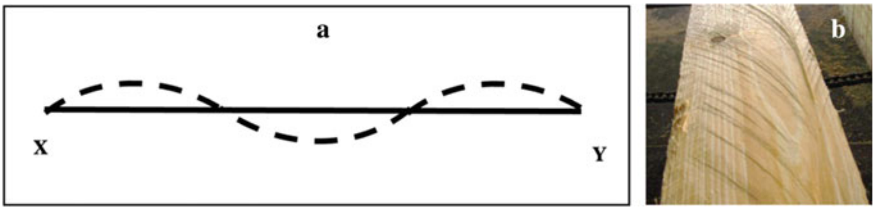

Fig. 8.2 **a** Theoretical trajectory of cutting and real trajectory of a saw with loss of tension. **b** Sawn wood with low surface quality, surfaces with cut marks. Trejo et al. (2018)

temperatures, burned parts, increased cutting forces, increased deformation on the saws, excessive power consumption, overheating of the motors and the cutting tool, and in some cases can be reached a cutting process violent and dangerous. There is a close relationship between eco-efficiency and business competitiveness, because while companies act creatively and respond to environmental demands, they not only reduce waste and use resources more efficiently, but also streamline their production processes, reduce costs, improve the quality of their products, and take the leadership in front of other companies, making themselves more competitive (Taylhardt 1998).

8.1.3 Energy Consumption in Cutting Wood

The more advanced approach in cutting wood requires constant monitoring of the cutting process in real time, which can be done by measuring different process outputs. The amount of heat generated during cutting, the cutting forces and the power consumed are common examples of the cutting process performance (Svrzic and Danon 2015). These authors, point out that the monitoring of the cutting process is essential for many technological reasons, such as surface quality, cutting tool condition, energy consumed, machine wear and optimal use of time with respect to the cutting program.

$$E_c = E_t - E_i \tag{8.1}$$

where E_c = cutting energy, E_t = total energy, E_i = energy for idling movements of the saw (turn the tool). Therefore, the intensity of the current in amperes (A) measured in certain cutting conditions allows to estimate the average mechanical power in Watts (W). However, in real operating conditions it is important to work with values of the energy consumed for the cut (E_c), since being the parameter of greater magnitude, will directly affect the performance of the motors, electrical protections and, therefore, in the design of the motors and the global consumption.

8.1.4 The Wear of the Cutting Tools

The wear is a tribological phenomenon, which occurs when two bodies, subject to a load, are in contact and in relative motion, and due to the friction between the cutting tool and the wood or the wood-based, makes it a progressive process as a function of the work done (Trejo et al. 2020). It can be defined as the progressive removal of material from a surface in relative movement in relation to the agent causing said removal (Díaz 2007).

With the evolution of the wear, the actions resulting from the increase of the cutting effort and the cutting temperature increase what increases the effect of the loss of tension in the cutting tools, which shows the importance of knowing the exact moment for the saw change. However, the stopping operations to perform cutting tool changes at premature stages of the wear curve also have consequences associated with the reduction of the productivity of the sawmill, reduction of the service life of the cutting tools when they are sharpening, when they still have the capacity to cut, increases in supplies for sharpening and in working hours men.

Knowing the exact timing for changing the cutting tools in a sawmill is important. In most of the industries this operation is carried out empirically, some of them have standardized tool changes in changes of work shift or volumes of standard production with very distant values of the industries. Generally, the changes are made when it is too evident in the saw's operation and the product's quality, always with the main objective of maximizing productivity. It would be advisable to replace cutting tools at scheduled maintenance stops and ideally do not stop the machinery to change the cutting tools.

8.1.5 The Theory of Inventive Problem Solving (TRIZ)

TRIZ is a tool developed under the leadership of Genrich Altshuller. It has first been announced in 1956 but is still not widespread around the world known. Altshuller developed the theory through the analysis of a million and a half invention patents, which he then filtered by keeping only 200,000 of that, trying to find only the inventive problems and the way it was solved.

Of these, only 40.000 patents were considered inventive, the rest were only improvements. The theory was proposed to Stalin as a tool to improve Soviet technology. Altshuller, its creator, was considered critical of the regime and sent for a Gulag. During the time he spent in jail, he perfected his theory, giving rise to TRIZ.

His idea was to develop a systematic and creative method to solve problems involving the resolution of contradictions in technical systems, what is, the solution to one problem could rise another problem, and when its contradiction was solved, the solution to the problem would be closest of the Ideal Solution (Savransky 2000).

In TRIZ, the Particular Problem is at a higher level relative to a Standard Problem of an analogous or similar nature with a known solution or a Standard Solution to obtain the solution to the specific problem or the Particular Solution (Fig. 8.3).

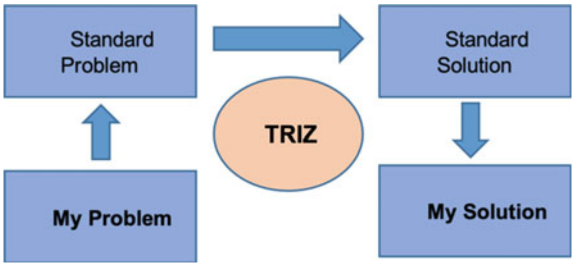

Fig. 8.3 TRIZ troubleshooting scheme. Adapted from Savransky (2000)

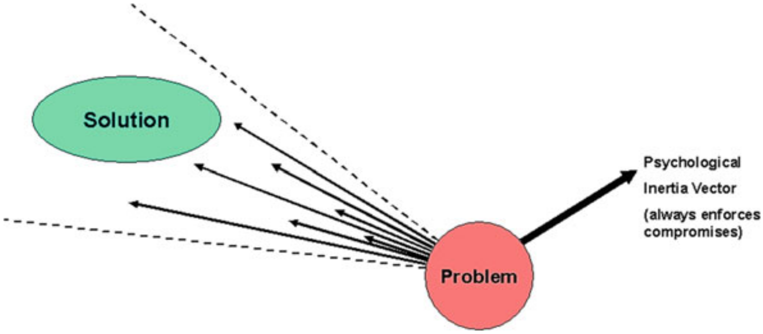

Fig. 8.4 The search for solutions with and without the TRIZ approach (Loebmann 2002)

The real advantage of the TRIZ methodology is, that you are enforced to find the ideal solution (Fig. 8.4), because you are able to burst the psychological inertia barrier. So, you are at first able to solve all the contradictions of the basic system problems without accepting trade-offs as it happens with all the other classical trial and error creativity methods.

The TRIZ method allows employees themselves and even external guests to find opportunities for improvements in small and medium-sized companies that are looking for new ideas to boost their business. TRIZ, as a science, proposes to solve problems with a high level of abstraction. It determines and categorizes the regular aspects of the technical systems and technological processes that need to be improved, as well as the inventive process to achieve the expected improvement. A systematic and analytical methodology is reinforced with several tools that promote the creative thinking and the solutions efficiency, because it emphasizes the extrapolation of specific problems to standard problems with known solutions or solutions applied in other areas (Savransky 2000).

The TRIZ tool can also be used as an intermediate strategy that, together with other techniques or methodologies such as LEAN or ECO, allow finding possible solutions that lead to meeting the required objectives or improvements to systems in terms of energy loss, loss of information, loss of time, reliability, productivity and amount of waste of materials and consumables (Muiambo 2019).

8.2 Method Application

8.2.1 Innovation Situation Questionnaire (ISQ)

To analyze the problem, it was opted to use the Innovation Situation Questionnaire (ISQ), described by de Carvalho et al. (2012). The ISQ is a tool that can be used as an instrument to analyze and describe the problem, through the complete exploration of the studied system.

For this, it is necessary descriptive information about the system that needs to be improved, and collect basic data about the system, such as name, function, structure, operation, and related areas. List available resources that are not always used or that may have other participation in the system, such as chemical resources, fields (electric power, gravitational potential), current space, time, information, and function. It is necessary to obtain information about the problem to be eliminated and to describe its participation in the situation, the mechanism that causes the problem, the history of its evolution and other associated problems that must be solved.

It should identify which modifications are allowed by the system and its limitations. As criteria for the selection of conceptual solutions, it is necessary to identify the wanted technological and economic characteristics for the system, the wanted period and the expected innovation degree. It is important to have a history of attempts to solve the problem, which can be developed by conducting a study of the existent market products, identify the solutions that have been tried in the company and research patents. As described, for the problem analysis the ISQ was used, the application of this is detailed in the continuation.

I. **Information about the system**

System name and function: Sawmill. Its function is cutting of the wooden blocks into sawed pieces.
Structure and system operation: The main components of the system are the engine that rotates the axis. The axis where the saws rotate, which when rotating comes in contact with the wood by machining it in the required format. The feed system of the wood that will be sawn. The support structure of the machinery.
System environment: The saws interact with the wood cutting it, and interact with the axis that rotates these saws, the axis interacts with the engine that makes rotate it, and there is also the interaction with the ambience, causing the process to be influenced by the air, temperature, among others.

II. **Available resources**

Substances: Cutting saws, the axis, the feed table, the support structure of the machinery, the wood that will be sawing, sawdust generated in the cutting process, measuring instruments for maintenance (current intensity, temperature, among others), compressed air available in industries, maintenance supplies.
Fields: Ambient temperature, cutting disk temperature, gravitational field and power grid, among others.

III. **Information about the problem situation**

What improvements are wanted: The saws do not cut correctly when worn out, for that, it wants to obtain the information about when the saws need to be changed.

Other points that can be optimized: The service life of the saw can be increased.
Problem to be eliminated: Loss in the cutting quality, caused by the disk deformation, caused by the friction between the saw and the wood, the increase in the cutting temperature, the saws overheating, the motor overheating and the low productivity.

IV. **Modification of the system**

Modifications allowed and limitations on changes: It is possible to work on the engines, the environment, the axis and the support structure. The friction between the wood and the saws must be kept, the current system must be improved and not replaced, and the saws and the centrifugal force should not be modified, as the saw's rotation speed is associated with cutting parameters demanded.

V. **Criteria for selecting the conceptual solutions**

Identify technological characteristics: Should be prioritizing solutions that can be implemented in the current equipment.
Wanted economic characteristics: Should be a priority in the identification of the need to change the cutting tool, so that it can be changed before it starts to perform cuts without precision, since this causes losses in the wood quality and value.

VI. **Historic of attempts to solve the problem**

Previous attempts to solve the problem: Currently it is tried to minimize the problem through programmed changes, however, this method does not eliminate the problem, since the wear and the deformation of the disk are variable according to the meters of wood sawed and the condition of the wood to be sawn.
Other systems with similar problems: The problem also occurs in the machining of other types of material.

8.2.2 Interaction Analysis

Having identified the problem and knowing the system functioning, the functions of the main parts of the system related to the problem, the interaction analysis tool can be used to show more information about the system and the problem studied.

Mann (2001) says that in the interaction analysis, each element of the system is connected to others through interactions (functions) through graphs or tables. These interactions are put together in groups of beneficial or effective interactions, adverse or harmful interactions and interactions that do not significantly affect the system known as neutral interactions.

The main problems are associated with harmful interactions, especially those related to the main function of the system, therefore, when analyzing these harmful functions, important information of the problem can be identified, such as its root cause, influence of the elements of the system on the magnitude of the problem, among others, to find out appropriate solutions to the problem. The interaction analysis between the components of the system with the saw in good condition can be seen in the Table 8.1.

And the interaction analysis between the components of the system with the worn saw can be seen in the Table 8.2.

Table 8.1 Interaction analysis between the components of the system with the saw in good condition

–	Electric engine	Axis	Saw	Feed system table	Wood
Electric engine		(o) Spins			
Axis			(o) Spins		
Saw					(o) Gets into friction/(*) Cut into pieces
Feed system table					(*) Directs to the system
Wood			(x) Wears/(x) Saw heating		

(o) Neutral interactions. (*) Beneficial or effective interactions. (x) Harmful interactions

Table 8.2 Interaction analysis between the components of the system with the worn saw

–	Electric engine	Axis	Worn saw	Feed system table	Wood
Electric engine		(o) Spins			
Axis			(o) Spins		
Worn out saw	(x) Increases power consumption	(x) Increases mechanical stress			(o) Gets into friction/(x) Cut with nonconformities
Feed system table					(*) Directs to the system
Wood			(x) Wears (x) Saw heating		

(o) Neutral interactions. (*) Beneficial or effective interactions. (x) Harmful interactions

From the ISQ and the interactions analysis between the components with the saw in good and worn out conditions, it is observed that one of the main problems to be treated in the system is how to identify the moment when the "saw in good condition" becomes a "worn out saw", since at that point the number of negative interactions between the components of the system increases by 2.5 times (from 2 to 5). Another negative point identified to be worked on is the heating of the saw during the cutting process.

8.2.3 Inventive Standards

The inventive standards converge in that, if two problems result in identical problem models, they have identical or standard solution patterns (Savransky 2000). For this, it was necessary to analyze the 5 classes of the list of 76 standard solutions, that can be used knowing in detail the studied system, the problem that affects the system, the resources and fields that interfere and it is available, as well as their interactions. These inventive standards came directly from the laws of the evolution of technical systems, guiding the synthesis and transformation of these systems, eliminating implicitly its technical contradictions.

8.2.3.1 Identification of Saw Wear

To solve one of the problems analyzed, it is necessary to be able to identify the moment when the saws become "worn out", it is necessary to be able to do it while the saws are in operation, since from this moment will be generated products with low quality and consequently of less economic value. By identifying this moment where the change of the saw is necessary, it is avoided the use of worn saws and it is avoided that the saw is changed without necessity; it is generating a greater use of the saw, since it will be used during all its service life.

Relating the problem to the inventive standards: it is identified that the problem is associated with a "Measurement and Detection Standard" (Class 4) and its Group 4.2 "Synthesis of Measurement System", specifically with Inventive Standard 4.2.1, Salamatov (2005) points out that (Fig. 8.5):

> If a non-SFM is not easy to detect or measure, the problem is solved by synthesizing a simple or dual SFM with a field at the output. Instead of direct measurement or detection of a parameter, another parameter identified with the field is measured or detected. The field to be introduced should have a parameter that we can easily detect or measure, and which can indicate the state of the parameter we need to detect or measure.

For this, it can choose to measure the saw's wear through the electricity field (intensity of energy consumption), since with the wear of saws, the cutting effort increases and, therefore, increases the energetic demands of the process. In this way, a parameter of difficult measurement (saws's wear in operation) can be measured through an easy measurement field (electric intensity).

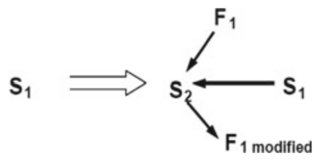

Fig. 8.5 Inventive standard 4.2.1. Use of an easy measurement field associated with a difficult measurement parameter Salamatov (2005). S1: Saw. S2: Wood. F1: Saw's wear. F1 modified: Energy intensity

For this, it can choose to measure the saw's wear through the electricity field (intensity of energy consumption), since with the wear of saws, the cutting effort increases and, therefore, increases the energetic demands of the process. In this way, a parameter of difficult measurement (saws' wear in operation) can be measured through an easy measurement field (electric intensity).

Trejo et al. (2020), points out that the wear process during the cutting of wood is a function of the effective cutting time or the cutting length, and is represented by a characteristic curve of the sigmoidal type known as the abrasive wear curve (Fig. 8.6).

Trejo et al. (2020), detail that the curves of Fig. 8.6a, b, are distributed into three major regions. At the beginning (zone I), the wear is accelerated with a logarithmic growth trend ($m_t \sim \text{const}\, t^{1/2}$), because the edge level is too thin and performs most of the actions, therefore, it is considered a short-term stage. This value tends to decrease with the work, the time, or the friction trajectory until it reaches a stable value with an almost linear growth trend in zone II ($m_t \sim \text{const}\, t$), what is known

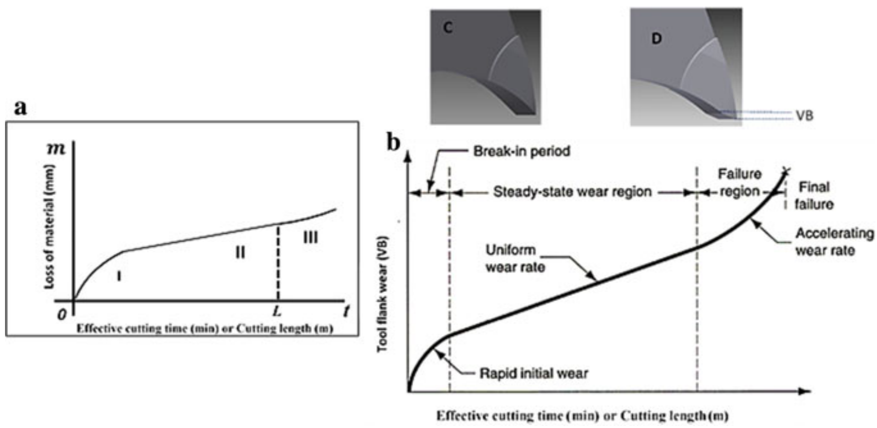

Fig. 8.6 Abrasive wear curves as a function of the effective machining time or cutting length (Trejo et al. 2020). **a** Working limit of the tool. **b** Tool wear as a function of cutting time. **c** Sharp-edged tooth. **d** Tooth with flank wear (VB). *m* is the loss of material due to wear (mm), *t* is the effective cutting time (min) or cutting length (m), and *L* is the working limit of cutting tools (m) before sharpening

as the zone of work until the limit of work of the cutting tool (L), at this point, the wear rate stabilizes for a time, until the difficulties to cut are increased too much. From this moment (zone III), the wear increases in an accelerated way and it is called catastrophic wear, characterized by a significant increase in the rate of wear with an exponential trend ($m_t \sim e^{\text{const}\, t}$). It is a stage that must be avoided because it affects the cutting tools, all the machinery, mechanisms, and the quality of the final product. Analogously, Aknouche et al. (2009) quoted by Ghosh et al. (2015) described the stages of wear such as running (abrupt wear), linear (stability period) and catastrophic wear (leading to tool failure). Similar tool life stages of the tool were explained in metal processing through Taylor curves (Trent and Wright 2000) quoted by Ghosh et al. (2015).

Trejo et al. (2015), points out that in experimental evaluations in sawmills with tape saws, significant increases in energy consumption were observed when the thickness of the chip was increased above the optimum value (thickness of the optimal chip), attributing this effect mainly to the increase of the cutting efforts on the wood. The result obtained theoretically through TRIZ, is supported, and can be demonstrated by the mathematic expression proposed by Antoine (1956):

$$F = a + b + \left(c' + c''\right) \tag{8.2}$$

where, $F =$ it is the parallel component to the cut force, $a =$ it is the cut of the fibers, $b =$ it is the double lateral shear, $\text{c}' =$ it is the transformation of the chip into sawdust and $\text{c}'' =$ it is the corresponding of tool's sawdust exit. Understanding that when the cutting edges have been lost due to wear, the tool loses the ability to cut the fibers (a), therefore, the parallel component to the cut force (F) is increased proportionately to wear.

In the proposed approach for Trejo et al. (2020), it was modeled the power consumption values from the pairs of points x, y, as a function of the accumulated cutting length, using a mathematical equation (non-linear adjustment model) that approximates these values to the abrasive wear theory (sigmoidal curve). The function was modeled using an equation developed by the authors (Eq. 8.3), which is composed of two parts. The first part reflects an exponential behavior of $f_{(x)}$ for the values of x, which has a greater incidence in the last stage of the curve formed in Fig. 8.6 (abrasive wear). In addition, a second part reflects the growth behavior of a pseudo logarithm (initial stages, zone I and II of Fig. 8.6). This part of the equation loses effect when x increases its values, the exponential part of the equation begins to be dominant.

$$f_{(x)} = \left(e^{a(1)x^3}\right) + \left(\frac{a(2)x}{x + a(3)}\right) \tag{8.3}$$

where, $f_{(x)}$ corresponds to the power consumption (kW); x the accumulated cutting length (m) and a is the vector of coefficients of the equation (optimization vector).

In that work, Trejo et al. (2020) point out that the first derivative of $f'_{(x)}$, is the instantaneous variation rate of y in relation to x. An inflection point occurs at a point in the function where the second derivative $f''_{(x)}$, because there is a change in the concavity of the curve at that point. At this point, it is proposed to integrate the algorithm (Fig. 8.7) presented by Trejo et al. (2020), in a data collection system during cutting (power consumption in the cutting), a system for processing and analyzing data in real time (unit intelligent and autonomous for decision making) and a response system for the operator/monitor of the cutting process, through a light signal that indicates when the working limit has been reached, which will indicate that the saw is worn and needs to be replaced, following the same principle of the Kanban method (generating a visual signal of attention) (Fig. 8.8).

Fig. 8.7 Pseudocode developed for the model

```
R(1,2,3)_xy = Read(data)
N = 1 : 1035
for n=1:3 do
    a = (5e^-9, 5, 1); D = N
    while D > ϵ do
        F_n(x) = e^(a(1)x^3) + a(2)x / (x+a(3))
        min[D = Σ_{k=1}^{N} (R(n)_xk − F_n(x_k))]
        Update(a)
    end while
    F2(x) = F̈_n(x)
    R_n = solve(F2(x) = 0)
    Plot(Fn(x))
end for
```

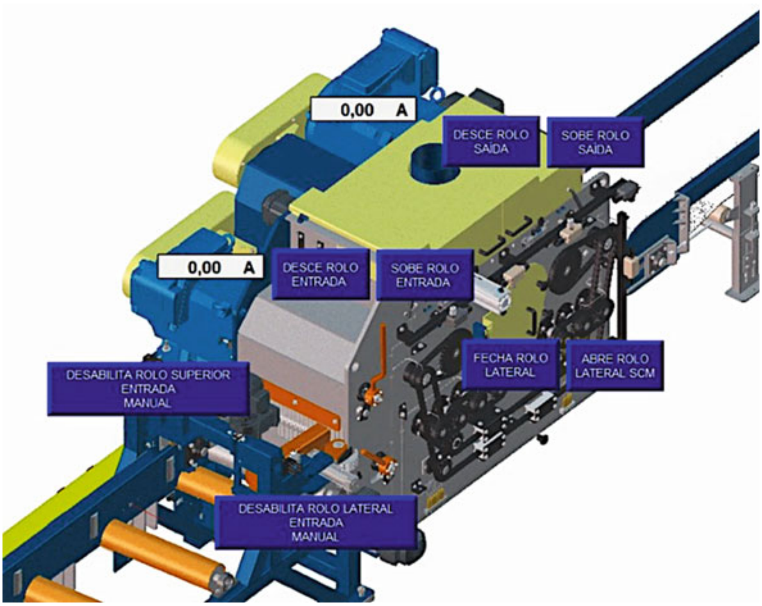

Fig. 8.8 Real supervisory system of a smart sawmill (sawmill 4.0). Courtesy of Todesmade Indústria de Madeiras e Artefatos Ltda and Mendes Maquinas, Brazil. Double axis circular saw

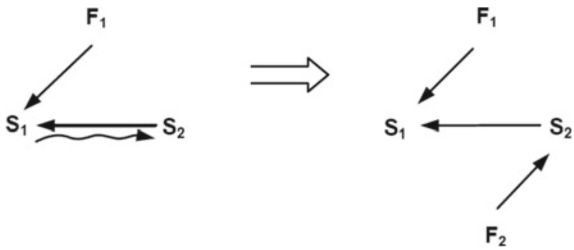

Fig. 8.9 Inventive standard 1.2.4. Introduction of a new field that neutralizes the harmful effect. Salamatov (2005). S1: Wood. S2: Saw. F1: Cutting heat. F2: Refrigeration field

8.2.3.2 Cutting Temperature Reduction

Salamatov (2005) says that it is necessary to use the available substances and fields available, low cost and easy implementation. Studying the inventive standards, connected to the saws heating problems, it is noted that it is associated to a "Composition and Decomposition of the Su-fields" (Class 1) and to its Group 1.2 "Decomposition of the Su-fields" and specifically to Invention Standard 1.2.4, Salamatov (2005) points out that (Fig. 8.9):

> If useful and harmful effects appear between two substances in a Su-field model, and a direct contact between the substances must be maintained, the problem can be solved by transition to a dual Su-field model, in which the useful effects is provided by the existing field while a new field neutralizes the harmful effect [...].

Compressed air is one of the most used resources in industries after electric power, because of its low cost, speed, and fast response to work. In metal machining, it is used as an air jet directly to the cutting zone and proves to be efficient to move particles in form of chips, in this way it reduces the cutting temperature and prolongs the tool life.

The use of compressed air jet in materials' machining has presented important results, which is especially true for metals' machining, which is intended to reduce conventional cutting fluids by the use of advanced techniques with a mix of small oils quantities for lubrication and compressed air for refrigeration (Frangoso 2017). In the Minimum Quantity Lubrication technique (MQL), as in the Cooling air and minimum quantity lubrication technique (CAMQL), the service life of the cutting tool is increased, and surface finish is improved with the compressed air cleaning system, in addition, a jet that is directly into the cutting zone is able to reduce the temperature in the region (Destro et al. 2011).

In this case, it is proposed to direct a diversion of the main compressed air network through the piping to the multiple disks saw in question, and internally in the saw on the disk train use a drilled piping to direct the compressed air into the cutting zone (Fig. 8.10b) close to a sprinkler irrigation system (Fig. 8.10a).

In this way, it is possible to force the chip and sawdust evacuation out of the cutting area (Fig. 8.10c), as well as reduce the cutting temperature and therefore the saws' heating, reducing possible disk deformations, making a rational use of tools.

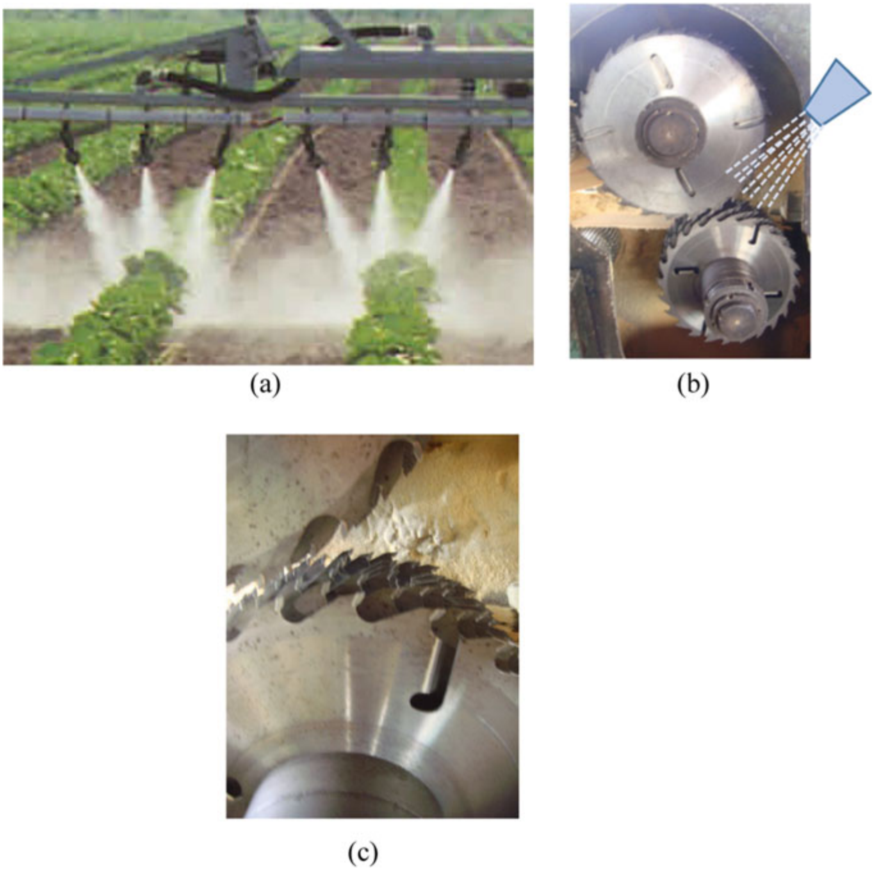

Fig. 8.10 **a** Sprinkler irrigation system. **b** Representation of the compressed air position in the disks. **c** Specific cutting zone between the disks. **a** Dos Santos (2018). **b–c** Authors (2018), double axis with circular saws in the sawmill

8.3 Conclusions and Future Outlook

This chapter proposes a case study about a machining system with the aim of improving a problematic situation presented in wood cutting at sawmills, using tools available from the Theory of Inventive Problem Solving (TRIZ). For this, it was used the Innovation Situation Questionnaire (ISQ) method, the Interaction Analysis between the system components and the relationships with the Inventive Standards proposed by Altschuller as a classic TRIZ tool, to identify the main problems, relationships, origins and propose solutions.

Among the problems identified, one corresponds to the measurement of one response parameter to the cutting process (saws' wear) and another problem is the heating of a part of the system (saws' heating). It was proposed to both, creative and original solutions based on the TRIZ approach, in which, it is recommended the use of the easy measurement field (electric energy consumption) associated to a difficult measurement parameter (wear of the cutting tool in operation). For the problem of cutting tool heating, it was suggested the inclusion of a new field that neutralizes the harmful effect, it is a refrigeration field that uses compressed air jet in the cutting disks, based on the available resources, it is cheap and easy to implement.

This is a small sample of the benefits of the application of TRIZ in manufacturing processes, in real operating conditions and to obtain improvements for process control. It is important to promote in the companies, teams with training in TRIZ, willing to break paradigms and open possibilities of optimization of their processes by means of unconventional but effective tools, which encourage the use of systematized creativity in solving many times similar problems and that converge in similar solutions, therein lies the biggest challenge for the diffusion of TRIZ in Latin America.

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Chapter 9
Solving Inventive Problems Dynamically: An Application of TRIZ with the System Dynamics Modeling Process

Jesús Delgado-Maciel, Giner Alor-Hernández, Luis A. Uscanga-González, Luis Alberto Barroso-Moreno, and Lizeth M. Rengel-Moreno

Abstract The competitiveness, the changing demands of the market, and a higher product complexity represent a challenge for inventiveness and innovation. The Theory of Inventive Problem-Solving (TRIZ) offers a set of tools to deal with problems modeled as contradictions, as a complex interaction among functions, or as the need to define the next step in a product, technology, or process. Despite the usefulness of TRIZ, this approach does not offer a guideline to select the most relevant problem, neither it is possible to evaluate the potential effect of a solution because TRIZ cannot analyze the behavior of a system or a function over time. Nevertheless, there is a tool capable of modeling systems with respect to time through simulations and contributing to overcoming some TRIZ limitations: The System Dynamics (SD). Also, SD provides analytical support to the models through the use of differential equations. This framework proposes a framework for solving inventive problems modeled through technical or physical contradictions in collaboration based on the

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SD approach. The result is an application of TRIZ that performs some simulations regarding time through the SD approach. The work includes a case study as a proof of concept during the conceptual design of a new product.

Keywords Conceptual design · Innovation · Contradictions · TRIZ · System dynamics · Simulation

9.1 Introduction

Companies face a market characterized by an increasing speed to accept new products and services. This evolution in the markets has changed the process for developing new products and services. Also, this phenomenon produces a market trend of shorter life cycles in products and services that must diversify and adapt their production systems to satisfy specific demands within a globalized market (King and Burgess 2006; Love et al. 2014). As a consequence, the above factors produce a context where inventiveness requires the support of new techniques to solve the intrinsic problems of developing new products or services.

The innovation management approach tries to solve the complex interaction of products and services with the purpose to create the conditions to satisfy the needs of the market and foresee the business evolution of an organization. However, the innovation process demands a creative activity, which is often perceived as a random and uncontrollable phenomenon. Therefore, it is necessary to develop an approach that allows to systematically deploy the process of creation of new products and services. Thus, the dynamic context in which companies and other organizations evolve has uncovered the need for a more efficient approach for problem-solving. For an enterprise, the need to control and guide the innovation process is a crucial capacity to remain in the market. For other organizations, the innovation process is the right strategy to provide value to society. In both cases, typical approaches for problem-solving have found their limits (i.e., brainstorming, analogical thinking, trial, and error). The natural transition to a more efficient method demands a new perspective on how people solve problems. Under this perspective, it is necessary to mobilize technical resources, scientific knowledge, and human capacities to propose more effective methods. In today's industrial horizon, the Theory of Inventive Problem-Solving (TRIZ) represents a useful approach to deal with some of the inherent problems of the innovation process. The goal of the Theory of Inventive Problem-Solving (TRIZ) is to offer a framework for modeling and solving problems where technical and scientific knowledge has a transversal application and becomes a resource to amplify creativity. The use of TRIZ in different domains and its interaction with other techniques make evident their advantages, but also unveil some of their limits.

The TRIZ toolbox enables a solver to deal with different conflicts such as (1) the analysis of physical and technical contradictions, (2) The capacity to model functions via the Substance-Field Analysis (SFA), and (3), the possibility to evaluate the current development of a technical system through a set of Trends of Evolution

(ToE). The main advantage of TRIZ is its ability to capitalize on scientific knowledge and transform it into inventive solutions. However, like any other problem-solving approach, TRIZ has several disadvantages, for instance:

- It does not have a tool to simulate systems.
- Its mathematical modeling is limited.
- In a situation when there is more than one problem to solve, TRIZ proposes no criterion for selecting the right conflict to settle.
- When there is more than one potential solution, the lack of a criterion to evaluate what alternative will produce more value increases the difficulty of the decision-making process.

The last two drawbacks are typical of several problem-solving techniques or processes. Thus, the identification of the right problem to solve, and the right solving path, facilitate the decision-making process, and consequently, improves productivity and efficacy. Despite their limits, TRIZ is one of the most effective approaches to solve inventive or innovation problems. However, the technique does not have a formal tool to make a dynamic analysis of the relationships or behaviors that exist in a system or its components (Tan et al. 2009; Fey and Rivin 2005; Jung and Lewis 2011). Hence, by applying the System Dynamics to TRIZ, it is possible to obtain new technical resources and tools to solve an inventive problem and facilitate decision-making. Besides, a feasible alternative to overcome, even partially some of the TRIZ limitations, is to combine TRIZ with other techniques. TRIZ is compatible with different techniques (Rantanen and Domb 2008; Yeh et al. 2011; Fu-Kwun et al. 2016; Sarno et al. 2005; Odair and Getúlio 2011; Bonnema 2011; Chulvi et al. 2013; Renev and Chechurin 2016) and in the context of this framework, the System Dynamics (SD) is a technique particularly useful and capable of contributing to the improvement of TRIZ. SD is an approach that allows the creation of dynamic simulation models based on causality relationships that change over time. Forrester (2013) and Sterman (2000) proposed a methodology to analyze and evaluate different policies during a simulation. At this point, it is important to underline that the implementation of TRIZ with SD is an emergent research topic. Next section offers a brief perspective on the central techniques of this article.

9.2 Background

According to (Savransky 2000), a pragmatic definition of a problem is the difference that exists between a desired condition and the current state. Hence, the problem-solving process consists of transforming some stages of the current situation into a desired situation. From a broad perspective, there are routine and non-routine problems. The main difference between them is that, in the former, there is knowledge of all the critical steps to find a solution. On the other hand, a problem is non-routine when at least one step is missing in the search for its resolution (Savransky

2000). Creative problems belong to the non-routine classification. TRIZ approach is linked to solving creative problems. A creative problem lacks obvious solutions when tackled or when available knowledge does not produce the desired result. Within the creative problems, there are the inventive problems, which have not defined the entry or exit steps in the search for their resolution. Furthermore, the complexity of the inventive problems lies in the fact that the solver has a lack of knowledge and in the difficulty of analyzing the relationship among their variables. Hence, he will be able to address the problem only if he has solved similar problems in the past. According to (Czinki and Hentschel 2016) there are simple and complex problems. The first reference to clear solutions and a known way of finding the solution, while the complex problems do not have a defined solution mechanism.

TRIZ is a useful tool to address creativity problems (Bertoncelli et al. 2016; Chang et al. 2016; Berdonosov and Redkolis 2015). The diversity of its applications includes innovation, engineering and design, among others. Fiorineschi et al. (2018) apply TRIZ in an area of conceptual design: Functional Decomposition and Morphology (FDM). This study provides a systematic framework for transforming a set of technical requirements into a product concept. Noor et al. (2018) use the TRIZ contradiction resolution method for the conceptual design of a kenaf fiber polymer as an automotive motor assembly.

The research uses a morphological chart to develop a systematic conceptual design for the component. However, when reviewing the TRIZ application literature, it shows that there are several disadvantages (the most relevant are listed in the introduction), mainly in concrete case studies (Renev and Chechurin 2016). These disadvantages (lack of a simulation tool and mathematical modeling limited) provides several areas of opportunity for the growth of the technique. On the other hand, some works apply SD to model problems related to the innovation process. The work of (Nieuwenhuijsena et al. 2018) carries out a dynamic simulation model that tests the automation process of vehicles through a complex innovation system. The main result was a sensitivity analysis that allows the evaluation of different scenarios to form different market strategies in the Netherlands.

The research of (Hsieh and Chou 2018) uses the System Dynamics approach to service innovation of Taiwan's SMEs. The simulation model aims to test the impact of globalization and the difficulties that some companies face to adapt their products to the market and to adopt Information Technologies (IT). The results generated strategies to increase competitiveness in the market.

Also, the work of (Xue and Xu 2017) analyzes the factors that influence the innovative capacity of companies that use information technologies. The research proposes a dynamic simulation model that tests business investment and the ability for assimilating computer innovation tools. The study considers companies in various sectors.

Table 9.1 shows some works that include TRIZ or SD techniques. Each article focuses on the innovation process. This table also shows the ability to model systems, research, and development (R&D), the use of simulation and the application in multiple domains.

Table 9.1 Work comparison

Author	System modeling	R&D	Multiple domains	TRIZ	SD	Simulation
Feng and Zhou (2022)	X	X	X	X	–	–
Kim et al. (2022)	X	X	X	X	–	–
Wang et al. (2021)	–	X	X	X	–	–
Cano-Moreno et al. (2021)	–	X	X	X	–	–
Sen et al. (2021)	–	X	X	X	–	–
Delgado-Maciel et al. (2020)	X	X	X	X	X	X
García-Manilla et al. (2019)	–	X	X	X	–	–
Noor et al. (2018)	–	–	X	X	–	–
Delgado-Maciel et al. (2018)	X	X	X	X	X	–
Čačo et al (2017)	–	X	–	X	–	–
Allena-Ozolina et al. (2017)	X	X	X	–	X	X
Becattini and Cascini (2016)	–	–	X	X	–	–
Wang et al. (2015)	–	X	–	X	–	–
Timma et al. (2015)	X	X	X	–	X	X

However, there are very few works involving TRIZ and SD methodologies to propose a new framework for problem-solving. The research of (Delgado-Maciel 2020) applies TRIZ and SD to evaluate a possible combination of both techniques that allow solving conflicts through the Substance-Field Analysis (SFA). In turn, the work of (Delgado-Maciel 2017) models the inventive archetypes of (Salamatov 2005) through a case study using SD. The result obtained is a simulation model for each archetype showing the Forrester diagram and the differential equations of the system. Table 9.2 shows some advantages of each tool demonstrating the compatibility between both techniques.

According to Table 9.2, both techniques are compatible. The advantages present in one technique complement the weaknesses of the other. Then, the subjacent hypothesis of this work states to use the SD methodology to solve inventive problems. Consequently, this framework demonstrates the feasibility of implementation the SD approach to TRIZ, to solve the intrinsic problems of the inventive process and its potential application in the conceptual design stage. The conceptual design stage

Table 9.2 Comparison between techniques

	Technique	
Advantage	TRIZ	SD
Focuses on inventive problems	X	–
Modeling over time	–	X
Use of simulation	–	X
Analysis of complex system	X	X
Based on differential equations	–	X
Application to innovation	X	X
Modeling functional analysis	X	–
Use of tools for problem-solving	X	–
Strong evaluation capabilities	–	X

is one of the more elusive and crucial stages of the innovation process (Tengku et al. 2011), which determines the uniqueness and originality of a product.

The case study depicts how to apply the SD methodology through a continuous simulation model programmed in the Stella© software with the solving process of TRIZ. The physical contradiction requires the simultaneous existence of two mutually exclusive states, corresponding to a single function or component of the system. The technical contradictions need the presence of two parameters that have a complex relationship that frequently leads to an impasse or a trade-off solution. From a general perspective, a contradiction arises when in a system, any attempt to improve, modify or transform a useful parameter causes the unacceptable degradation of itself or to another parameter also valuable and vice versa. The tools for solving contradictions have extensive use in the industrial and academic domains (Chechurin 2016), a condition that facilitates the adoption of new tools by the user, which is the case of an implementation of SD methodology to the TRIZ approach. Next section describes this application.

Finally, this framework only involves, the analysis of physical and technical contradictions. Consequently, the most important delimitation of the framework proposed in this framework is that it does not consider the formulation of inventive problems through the Substance-Field Analysis (SFA) or the Trends of Evolution (ToE).

9.3 Implementation of SD to TRIZ

Nowadays, TRIZ and SD are independent techniques, with separate methodologies. Sterman (2000) proposed the current methodology of SD through four phases: (1) Conceptualization, (2) Formulation, (3) Evaluation, and (4) Implementation. Table 9.3 describes the activities in each phase. The SD methodology encompasses some theoretical, mathematical, and continuous simulation fundamentals. Each phase

Table 9.3 SD methodology stage and activities

Conceptualization	Formulation	Evaluation	Implementation
1. Selection of the scenario	1. Elaboration of the Forrester diagram	1. Simulate the model and test the relationships of the causal diagram	1. Present the model in a form accessible to the user
2. Define the purpose of the model	2. Determination of the mathematical equations	2. Test the model under different assumptions	2. Observe and analyze the behavior of the model under different policies
3. Identify the critical variables and the limits of the model	3. Estimate and select the parameters of the model	3. Document the response of the model with sensitivity analysis	
4. Set the time horizon			
5. Establish the relationships between the variables			
6. Develop the causal diagram			

allows the user to create dynamic simulation models. The stages of development range from the theoretical approach (conceptualization) to the application by the end user (implementation).

TRIZ also has a methodology for the analysis of contradictions. According to (Altshuller 1999; Salamatov 2005), a successful strategy for solving inventive problems model as contradiction involves four TRIZ concepts:

1. The use of the contradiction matrix (Altshuller 2002) for technical contradictions or the use of separation principles in the case of physical contradictions
2. The concept of resources
3. The concept of an ideal system
4. The use of scientific effects.

The selection of the initial tool for solving a contradiction depends on the nature of the conflict and the model that better fits the conflict, but also, the selection calls for the knowledge and experience of the solver (Altshuller 1986; Savransky 2000).

Figure 9.1 shows the methodological proposal to apply SD to TRIZ, focusing on the solution of inventive problems model through physical or technical contradictions. According to (Altshuller 1999), the concept of contradiction is one of the most successful strategies to identify, model, and solve inventive problems. Thus, according to the TRIZ philosophy, an inventive problem has at least one contradiction. The methodology has three phases: Definition, contradiction analysis, and development. Next section describes each phase.

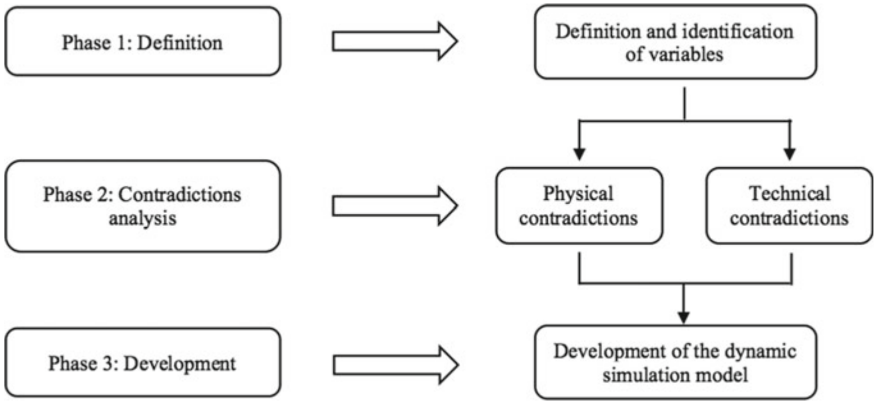


Fig. 9.1 Implementation of TRIZ to SD

Phase one: The first phase comprises an initial analysis of variables. This stage only involves the conceptualization phase of Table 9.3. SD suggests using a Causal Loop Diagram (CLD). The CLD is an oriented graph. An arrow represents the causal link between the variables it connects. A link has a polarity, which denotes the influence: positive or negative. In a CLD there are negative (balancing) and positive (feedback) loops. The balancing loops are used to stabilize the system while the feedback loops give growth to the system. The model of a complex system will have several loops. It is important to establish in this phase a mechanism to classify and prioritize loops according to their importance. Any ranking tool is feasible; however, the Analytic Hierarchic Process (AHP) has several advantages that make it a great alternative. Hence, the AHP allows the user to decide the most important loop to start the solving process. It is important to underline that each loop in the CLD refers to at least one contradiction. Hence, the variables or parameters that form a loop in the diagram are the sources of at least one contradiction. It is possible then to formulate a physical or technical contradiction from the loop analysis. If the solver perceives a physical contradiction, then a basic structure is useful to model the problem: The characteristic, state or parameter demands the condition "A" to accomplish the effect "X" but the opposite state "Anti A" to avoid, guarantee or improve the condition "Y". To model a technical contradiction (Savransky 2000) offers the next structure: "The key subsystem (name) should be or has ("positive" parameter), in order to (the first requirement for the tool), the key subsystem (name) should not be or not have ("negative" parameter), in order to (the second requirement for the tool)". The definition stage transforms the information available in each loop to a set or at least one contradiction. The experience and ability of the solver decide the nature of the conflict as a physical or technical contradiction. Later, the first TRIZ tool deployed is the Ideal Final Result (Altshuller 1999). The goal of the ideal final result or a more desired result derives from the ideal system concept. An ideal system does not exist physically, does not consume energy or matter, but provides at least one useful function without any loss and harmful effects. This utopic concept has the power to concentrate the cognitive effort in one common direction. It creates a purpose shared by all stakeholders in the solving process.

Phase two: The second phase focuses on the analysis of physical and technical contradictions with the goal to define potential solving paths. As mentioned before, the sources of this information are the loops described in the causal loop-diagram. Thus, more loops are equal to more conflicts. The synthesis of the available information produces a network of problems that have complex and even hidden relationships. The hierarchy proposed in the previous phase is convenient to classify problems or loops with the goal to guide the effort in one direction, but also to define the dynamic hypothesis. The SD allows the user to observe the behavior of the system over time whenever there is any change in the variables. A dynamic hypothesis represents a potential change in the system. It is important to notice that if it is not possible to offer any feasible solution from the contradiction analysis there is an alternative tool to the contradiction matrix of (Altshuller 2002) and the separation principles (Altshuller 1986): The Algorithm of Inventive Problems Solving (ARIZ) which offers a unique sequence to apply the TRIZ tools (Altshuller 1999). The use of ARIZ in this work is just a recommendation. The study and analysis of this algorithm are out of the scope of this work. The information concerning the system components (produced in phase one) is helpful to apply another TRIZ concept: resources. According to TRIZ, all systems providing at least one useful function evolve continually through the use of their intrinsic resources. The solving strategy must then make use of resources already available in the system or the surrounding environment. A resource is something in the system not fully exploited or underestimated, but is potentially accessible to produce value without excessive cost. TRIZ considers that the system resources are the raw material for an inventive solution. Savransky (2000) offers a complete resource classification.

Phase three: Many steps of Table 9.3 results in the final phase three of the implementation of SD to TRIZ. The creation and application of a simulation model allow the mathematical analysis of the previous phases. The integration of the dynamic simulation to TRIZ represents a significant contribution. Sensitivity analysis provides the user with information that facilitates decision-making due to the ability to test different policies. In this phase, the dynamic hypotheses represented in the CLD have an essential role because they give the ability to analyze different scenarios and evaluate the best solution alternatives.

Next section depicts the application in a case study. To define the case study, a quick survey proposed to postgraduate students of a Management Engineering Master isolated an object that has several undesired functions: The umbrella.

9.4 Application in a Conceptual Design

The case study selected to apply the TRIZ+SD methodology comprises the analysis of a common object: An umbrella. The methodology allows analyzing the system to identify some conflicts and then testing its behavior through a simulation model created in the Stella© software.

9.4.1 Definition and Identification of Variables

The function of an umbrella (subsequently named as the object) is to divert as many drops of rain from point O (Fig. 9.2) or to block sunlight to any object under the ratio r. The object can be in movement or rest in one position. The efficiency of the object depends on the percentage of which its function is fulfilled when it is in operation. The main variables and attributes of the object are its radius, thickness, and length. These parameters determine the physical dimensions and size of the object. Figure 9.2 shows them graphically.

Figure 9.3 shows the components of the object extracted from US patents US005195550A and US006209556B1.

The problem comprises identifying which characteristics are more significant in the analysis of the object. Hence, it is necessary to identify the primary and secondary functions of the object, and then, to rank these functions. The use of the Analytic Hierarchy Process (AHP) is useful to accomplish this task (Ho and Xin 2018; Khaira and Dwivedi 2018). The information of the object is usually obtained with a market study or through benchmarking (Terninko 1997). A panel of experts conducted a benchmarking of different similar objects available in the market to carry out the AHP. The panel involves five experts: two designers, two users, and a purchasing expert. Table 9.4 shows a description of the characteristics of the object and Table 9.5 shows their weight and relative importance.

Table 9.5 shows the primary weights and a consistency index of 0.09. This value falls within the ranges established by Saaty (2014).

The user proposes the conditions (Fig. 9.2). The object is a portable umbrella, not a fixed one. For the case study, the upper limit or maximum measures are:

- Length of the object (L) must not exceed 200 cm, which corresponds to the bigger portable umbrella in the market, which is a portable object used outdoor ($L \leq 200$ cm).
- The radius of the object (r) must not exceed 100 cm ($r \leq 100$ cm).

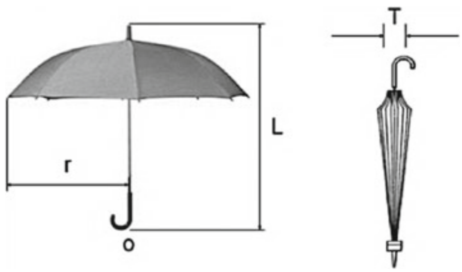
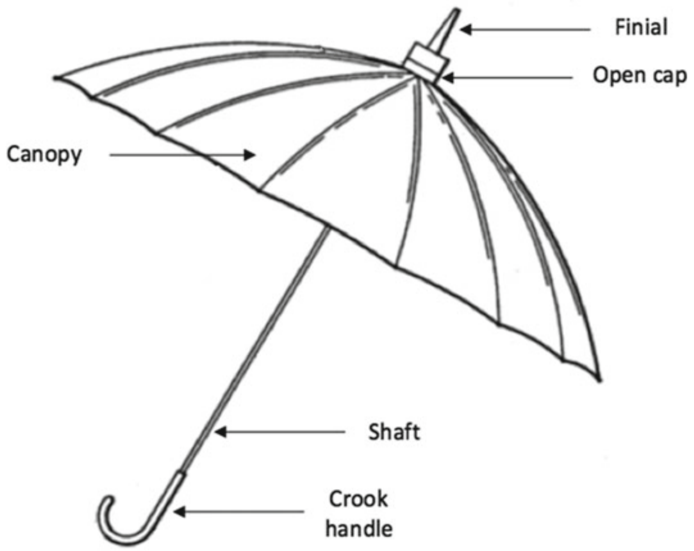


Fig. 9.2 Main variables



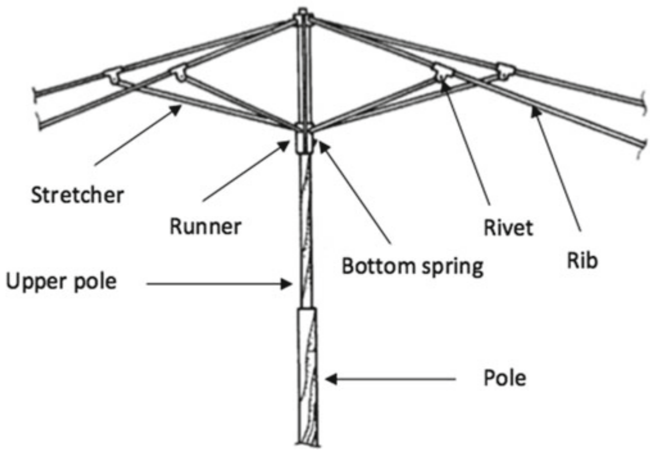


Fig. 9.3 Object components (USPTO, US005195550A and US006209556B1)

- The thickness of the object when is not in use (T) must not exceed 15 cm ($T \leq$ 15 cm).

The primary problem is to analyze a portable umbrella using TRIZ and SD in two different instants. The analysis allows the user to change the design of the object to improve its efficiency and test it over time by solving physical and technical contradictions.

According to Fig. 9.2, the three critical variables in the object are thickness (T), length (L) and radius (r). These variables (measured in centimeters) are auxiliary

Table 9.4 Description of characteristics

Characteristics	Description
Esthetics	Shape and physics characteristics of the object
Portability	Movable and easy to transport
Stability	Ability to maintain balance
Storable	Ability to save an object easily
Thickness	The state of being thick the object when this is not in use
The area covered	Amount of space protected from rain or sunlight

Table 9.5 AHP analysis

Primary characteristics	Primary weight	Consistency index
Portability	0.430	**0.09**
Thickness	0.267	
Esthetics	0.123	
Storable	0.089	
The area covered	0.053	
Stability	0.038	
Summation	**1.00**	

and are crucial to building the CLD. The state or level variables (which generate differential equations) refer to dimensionless percentages, which are: Efficiency of the function and the analysis of the area. The average maximum value for a portable sunshade is 60 cm at the radius and 70 cm for the length. These measures are common in umbrellas available for sale, and they are within the ranges established above ($L \leq 200$ cm, $r \leq 100$ cm, and $T \leq 15$ cm). The case study considers higher values to those measures as upper limit mentioning an almost static object.

Establishing the time horizon is essential. In dynamic simulation models, the time that elapses is the main variable, since it is considered a simulation of continuous events. The user can choose the number of years to analyze and observe how the efficiency increase or decrease over time. The time selected for this model is five years. This period was chosen due to the analysis of patents per year of the product. The European Patent Office and the United States Patent and Trademark Office databases were the sources of patents. The codes A45B19, A45B22, A45B23, and A45B25 are useful to explore some patent tendencies. The patents considered in this study show important changes in the design in the last thirty years. Figure 9.4 shows the number of annual patents since the '70s. The most significant changes are shown with an average of five years.

The input variables (thickness, length, and radius) are those that the user can control from the interface created in the simulation. These are related to the level variables that measure the efficiency percentage of the object's function.

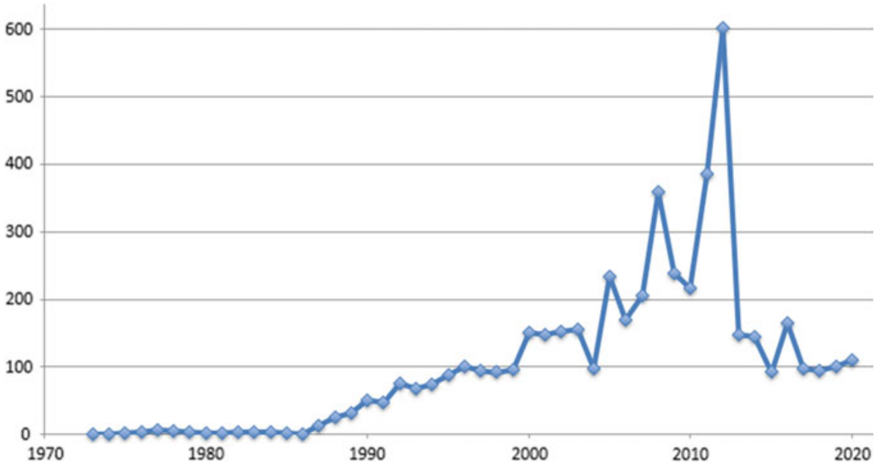


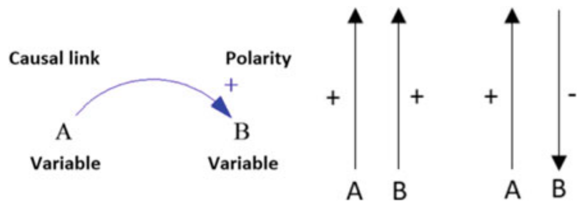
Fig. 9.4 Patents per year since 1970

The CLD uses oriented graphs to identify feedback loops and balancing loops. This relationship formed by at least two variables allows the identification of the loops. The polarity of the causal relationship can be positive or negative. Being positive implies that if variable A increases, variable B will do so too; and else, if variable A decreases, so will variable B. On the other hand, in a negative influence: if variable A increases, variable B decreases; and if variable A decreases, variable B increases (Fig. 9.5). The importance of them is the analysis of the complexity of the system and the capacity of balancing or feedback of the same. Figure 9.5 shows the relationship between two variables.

Figure 9.6 shows CLD. There are two loops: Feedback loop (represented by 'R') and balancing loop (represented by 'B').

Figure 9.6 shows two important loops. Regarding the first loop (R), if the percentage of area covered by the object increases, the efficiency of the function increases and vice versa. In the balancing loop (B), increasing the efficiency of the function reduces the percentage of portability and vice versa. There are two variables in the first loop: (1) the percentage of the area covered, and (2) the percentage of the efficiency of the function. The relation of both variables constitutes a feedback loop, which moves the system to expand its useful function. The increment is the natural consequence of one variable over the second one.

Fig. 9.5 The relation between two variables (Sterman 2000)



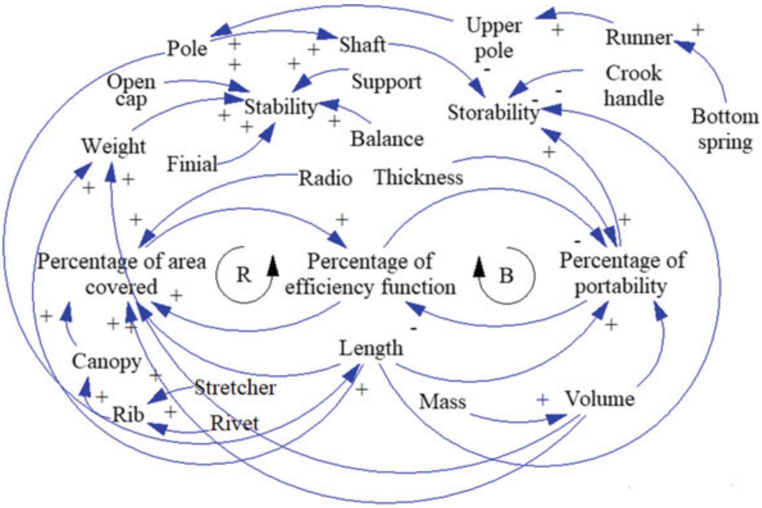


Fig. 9.6 Causal loop diagram

A balancing loop must have negative polarities and moves the system to a stable condition and later, to equilibrium. It is worth mentioning that the loops have an important role since it is in them where the physical and technical contradictions reside, as will be seen later on.

An ideal system is a utopic state. The efficiency of the system during the operation time does not have any loss and corresponds to 100%. This state does not generate costs or occupy space or volume in space. The object analyzed, should divert 100% of raindrops while operating, must adapt its shape to the user requirements, and should be portable both in its operation and in its resting state. The selection of the most important loop to start the solution process is based on the AHP rank (see Table 9.5). According to Fig. 9.6, both loops generate at least one contradiction. Table 9.5 shows that the secondary characteristic with the highest weighted importance corresponds to the radius. Consequently, the feedback loop (R) represents the contradiction with the highest priority in the search for its solution.

The causal diagram shown in Fig. 9.6 shows that there are two contradictions: one technique and another physic. The feedback loop and the balancing loop contain the technical contradiction, since "if the radius increases the efficiency of the function increases, but portability decreases" evaluating area against portability. To get the physical contradiction is necessary in evaluating only the area and comparing it against itself in the feedback loop. The resulting approach is "the area of the object must be large when it is in operation but small when it is not." The next stage of the methodology contains the analysis of contradictions.

9.4.2 Contradiction Analysis

9.4.2.1 Physical Contradiction

The AHP analysis assists the user to rank the loops according to the most relevant requirements, and thus, to facilitate decision-making in the problem-solving process. The analysis of physical contradictions is a complex activity. It contains the study of a single parameter, which demands different logical status and different physical principles to operate. As a result, the emergence of a physical contradiction in a system increases the complexity of the solving process because it demands a reasoning process which frequently leads to an impasse. For the physical contradiction, the variable to analyze is the area. The positive effect occurs while the umbrella produces its useful function. The negative effect happens when the umbrella is inactive. The area depends directly on the radius of the object. Hence, physical contradiction is "The area of the object must be large when the object is in operation but small when it is not" (see Fig. 9.7).

According to (Savransky 2000) "if mutually exclusive requirements are demanded from the key subsystem, the separation in time is possible when a requirement exists (or made larger) at one period and absent (or made smaller) at another time interval. To apply this separation heuristic, answer the following question: Do we need the parameter to be "positive" and "negative" at all times, or is there some time interval(s) during which it is not necessary? If such an interval exists, it might be possible to separate the opposite requirements to the key subsystem in time". The separation principle in time is the most appropriate because there are two different states in two different periods. The object must have specific physical characteristics (dimensions) while it is exercising its function and different ones when it is not doing so. The above produces a separation in two different time instances as Fig. 9.7 depicts. However, this solution is not enough to satisfy the user requirements, which ask for a radius

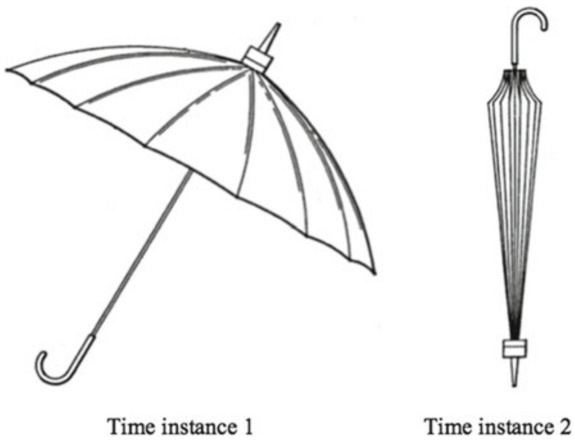


Fig. 9.7 Physical contradiction (US005195550A)

that modifies its length to satisfy different requirements without compromising the useful function.

According to the TRIZ approach, a system tends towards its ideal by ensuring useful functions without generating useless or harmful functions at no cost. Hence, any technique in constant evolution has available resources that can improve its operation and move the system closer to its ideal state. According to (Savransky 2000), there are height resource classes: environmental (natural), time, space, system, substance, energy, information, and functional resources. The use of available resources to solve technical problems produces inventive solutions. Table 9.6 makes a relation between each component and its most relevant resources. Table 9.6 lists the most relevant resources in each component. The purpose of this table is to create an inventory of some potential reserves to take into account during the solving process. The next TRIZ tool is the concept of an ideal system.

The concept of an ideal system plays a crucial role in the modeling and solving process. By definition, an ideal system is a system that does not exist, and yet the useful function(s) is secured and delivered by the system. An ideal system is a system that does not generate costs, does not occupy space or volume in space, and its efficiency is 100% without any loss or waste. The concept of an ideal system is useful to propose the best scenario, which has the benefit to focus the individual's effort in a common direction. Also, it is useful to propose key performance indicators. The introduction of the ideality concept in the modeling process enables the basic problem-solving process of TRIZ, which involves three concepts: (1) to model a conflict as a contradiction and link it to a solving principle (inventive or separation principle according to the nature of the contradiction). (2) To define the ideal solution to guide the solving effort, and (3) to use the available resources in the system. Following this logic, the combination of the separation principle in time, the resources listed in Table 9.6, and the ideal system concept leads to the conceptualization of an ideal umbrella that is wholly portable and completely covers the user. Table 9.6 contains some relevant resources in the system. It is important to notice that the physical contradiction demands the modification of the area; hence spatial resources can offer a solution. The space resource column contains resources that directly affect the size and portability of the object such as the unused side of the canopy and different positions on the rib and stretcher. The challenge then is to find a way to transform available resources into potential solutions, while the logic behind the separation principle guides the reasoning process. To assist the user in this task, TRIZ suggests the use of scientific effects. If the solver knows what he needs, but he cannot identify how to implement a process, or materialize certain results, then the use of scientific effects is the tool to use. Scientific effects have three classes: physical, chemical, and geometric effects. According to (Savransky 2000) if the required action (properly) is to reduce or increase the area or length of a body at the same weight, is necessary to use any of the following geometric effects:

- Multi-story configuration
- Use figures with a variable section

Table 9.6 Identification of some resources in each system component

	Resources							
Component	Natural	Time	Space	System	Substance	Energy	Information	Functional
Finial	–	–	–	–	Plastic properties	–	–	Aerodynamic design
Open cap	–	–	–	–	–	Pressure	–	–
Canopy	Water, air flow	Changing shape	Unused side of the object	–	Flexible, rainproof, color	Resistance (air and light)	Capacity to display information	–
Shaft	–	–	–	–	Rigidity, metal properties	–	–	–
Crook handle	–	–	Inner space	–	–	–	–	Fasten to object
Stretcher	Force	–	Changes its position	–	–	–	–	–
Runner	–	–	–	–	–	–	–	Ability to slip
Bottom spring	–	–	–	–	–	Pressure	–	Brake to stretchers
Rib	–	–	Changes its position	–	–	Force	–	–
Pole	–	–	Intern cavity	–	–	–	–	–
Rivet	–	–	–	–	High resistance	Pressure	–	–
Upper pole	–	Telescopic principle	–	–	–	–	–	–

- Mobius strip
- Use the surrounding areas.

The rib and the stretcher can change its position, so the use of the surrounding areas is a possible solution to solve the physical contradiction. The area of the object will be affected by the use of the resource and its effects. The separation principle in time and its combination with resources and effects fits the analysis. The selected separation principle allows to examine the object in two instants of time, the use of resources and effects guide the user in the search for solutions in the physical contradiction. Phase 3 includes the application of it. Other than the use of the surrounding areas, a multi-story configuration also provides a possible solution. This effect can originate some suitable conceptual designs.

The analysis of the physical contradiction covers only the feedback loop. However, it does not consider the portability of the object because it depends on the weight and volume. To analyze both loops simultaneously is necessary to analyze the technical contradiction.

9.4.2.2 Technical Contradiction

Unlike the physical contradiction, the technical contradiction does not analyze isolated loops, but several loops are analyzed simultaneously. This contradiction involves the loop (R) and (B) simultaneously. The alternatives of solution can use two models. The first one only evaluates the first loop. The evaluation of an isolated loop in the physical contradiction generates a simulation model focused on the improvement of a single parameter. The second model takes into consideration both loops and gives the opportunity to analyze more complex relations in the model. There are several technical contradictions in the object. Table 9.7 shows some of them and the inventive principles suggested by the contradiction matrix. According to Table 9.7, there are five important technical contradictions. For this case of study, the only volume against area will be taken into account. Both variables involve the efficiency of the function and portability. Thus, the technical contradiction expresses that "If the efficiency of the function increases then the portability decreases."

Table 9.7 Technical contradictions

Technical contradiction	Parameter 1	Parameter 2	Inventive principles
1	Efficiency	Volume	15, 19, 14, 4, 3
2	Volume	Area	17, 4, 7, 1, 31, 5
3	Stability	Volume	24, 5, 39, 35
4	Shape	Area	4, 17, 5, 2, 14
5	Volume	Weight	31, 35, 40, 2

The parameter to improve is the volume of the umbrella (technical contradiction 2) since both involve the input variables of the simulation. Hence, to analyze the percentage of area, it is necessary to define the dimensions of the radius, and for an analysis of the percentage of portability, it is needed to know the volume of the object. The parameter to improve is the volume of a moving object (parameter 7 of the contradiction matrix (Altshuller 2002)) since portability and weight of the object depends on it. There is an increase in mass and therefore an increase in volume. This results in an increase in weight. The weight is not part of a loop, it is a simple causal relationship, and therefore, both weight and mass are considered auxiliary variables in the CLD.

There is a relationship between the restrictions of the dimensions of the object. A fixed umbrella (used for garden or beach) has an average size of more than 2 m in length and a radius greater than 1 m (US2661752A). Because the object must be portable, the maximum measurements are 2 m of length, 1.05 m of radius, and 0.15 m of thickness.

The contradictions matrix has these parameters: parameter 7 (volume of a mobile object) is compared with parameter 5 (area of a mobile object).

The contradictions matrix comprises 39 parameters. Figure 9.8 presents a fragment of the contradiction matrix with the described parameters.

According to the matrix, the intersection of cells contains some of the inventive principles. To solve the contradiction volume against area, the inventive principles are 17, 4, 7, 1, 31 and 5:

	Worsening Feature → / Improving Feature ↓	Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Area of moving object	Area of stationary object	Volume of moving object	Volume of stationary object	Speed	Force (Intensity)	Stress or pressure	Shape	Stability of the object's composition	Strength	Duration of action of moving object	Duration of action of stationary object
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Weight of moving object	+	-	15, 8, 29,34	-	29, 17,	-	29, 2, 40, 28	-	2, 8, 15, 38	8, 10, 18, 37	10, 36,	10, 14,	1, 35, 19, 39	28, 27,	5, 34, 31, 35	-
2	Weight of stationary object	-	+	-	10, 1, 29, 35	-	35, 30,	-	5, 35, 14, 2	-	8, 10, 19, 35	13, 29,	13, 10,	26, 39, 1,	28, 2, 10, 27	-	2, 27, 19, 6
3	Length of moving object	8, 15, 29, 34	-	+	-	15, 17, 4	-	7, 17, 4, 35	-	13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29	1, 8, 15, 34	8, 35, 29, 34	19	-
4	Length of stationary object		35, 28,	-	+	-	17, 7, 10, 40	-	35, 8, 2,14	-	28, 10	1, 14, 35	13, 14,	39, 37, 35	15, 14,	-	1, 10, 35
5	Area of moving object	2, 17, 29, 4	-	14, 15,	-	+	-	7, 14, 17, 4		29, 30, 4,	19, 30,	10, 15,	5, 34, 29, 4	11, 2, 13, 39	3, 15, 40, 14	6, 3	-
6	Area of stationary object	-	30, 2, 14, 18	-	26, 7, 9, 39	-	+	-		-	1, 18, 35, 36	10, 15,		2, 38	40	-	2, 10, 19, 30
7	Volume of moving object	2, 26, 29, 40	-	1, 7, 4, 35	-	1, 7, 4, 17	-	+	-	29, 4, 38, 34	15, 35,	6, 35, 36, 37	1, 15, 29, 4	28, 10, 1,	9, 14, 15, 7	6, 35, 4	-
8	Volume of stationary object	-	35, 10,	19, 14	35, 8, 2, 14	-		-	+	-	2, 18, 37	24, 35	7, 2, 35	34, 28,	9, 14, 17, 15	-	35, 34, 38
9	Speed	2, 28, 13, 38	-	13, 14, 8	-	29, 30, 34	-	7, 29, 34	-	+	13, 28,	6, 18, 38, 40	35, 15,	28, 33, 1,	8, 3, 26, 14	3, 19, 35, 5	-
10	Force (Intensity)	8, 1, 37, 18	18, 13, 1,	17, 19, 9,	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13, 28,	+	18, 21, 11	10, 35,	35, 10, 21	35, 10,	19, 2	
[illegible]	[illegible]	10,	13,	35,	35, 1,	10,	10,	6, 35,	[illegible]	6, 35,	36,	+	35, 4,	35,	9, 18,	19, 3,	

Fig. 9.8 Fragment of the contradiction matrix (Altshuller 2002)

17: Another dimension: Move to an object or a system in two or three-dimensional spaces. Use a multidimensional array of objects instead of an array that only counts.
4: Change of symmetry (asymmetry): The change of shape of an object and a system of its symmetry or asymmetry.
7: Nesting (the nested doll Matrushka): Place each object in turn within another. Make one-part pass through another's cavity.
1: Segmentation: Divide an object or a system into independent parts. Make an object accessible to disarm.
31: Porous materials: Make an object porous or add porous elements (inserts, coatings, etc.).
5: Merging: Bring closer together (or merge) identical or similar objects and assemble identical or similar parts to perform parallel operations.

The combination of the segmentation and nesting principles with the resources listed in Table 9.6 produces some solving paths to propose inventive solutions. The analysis made of the physical contradiction is similar to that of the technical contradiction. There are physical contradictions that are difficult to perceive or formulate, but the effect that they produce is reflected in the technical contradiction (Savransky 2000). The resources shown in Table 9.6 suggest that the segmentation and nesting principles are suitable for finding a solution because the technical contradiction also covers the area of the object. In turn, the portability of the object depends directly on the space resource. When analyzing Table 9.6, the resources that best adapt to the proposed solution in the model. According to (Savransky 2000), to select the correct resource it is necessary to evaluate the availability and the cost during the selection process, even subjectively. The user chooses the most appropriate principles and then tries to combine it with available resources (Table 9.6), so these principles are interpreted below:

7: Segmentation: It comprises dividing an object into independent parts; an umbrella operates with that principle in the design of the rods that give shape to the fabric.
1: Nesting: It is based on placing an object inside another, the umbrellas increase their portability when the main rod nests and with that its volume is reduced.

There is not any more loop to analyze. The loop analysis in Fig. 9.6 is finished.

9.4.3 Development of the Dynamic Simulation Model

The Forrester diagram (stock and flow diagram) shows the relationships between the variables that change over time and the states of the system. There are three different variables to build a Forrester diagram:

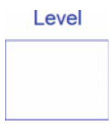
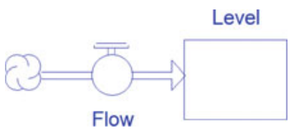
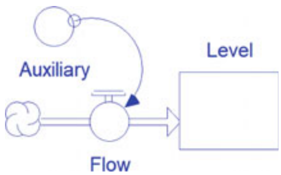
(1) State or level variables are considered flow containers. These variables change in their level depending on the inflows and outflows, that is, the “valves” that control the flows per unit of time.
(2) The valves are open depending on the mentioned “rates” or “parameters” and may not vary over the simulation time if they are predetermined in the initial scenario or change over time.
(3) The auxiliary variables can fluctuate and represent intermediate steps for the determination of the flow variables from the level variables.

Stella© allows the user to generate SD models through an interface to build Forrester diagrams. Table 9.8 contains the nomenclature used in Stella©. Also, Fig. 9.9 shows the Forrester diagram (FD). FD involves the auxiliary variables, the flows and the level variables (stocks).

The FD that analyzes the technical contradiction uses the multiple linear regression (MLR) as the tool to carry out the mathematical model. The model involves some independent variables, such as the efficiency of the function, length, and radius. Also, it considers the dependent variable, which is the percentage of the area covered. The MLR generates the mathematical information for the inflow relative to the efficiency of the function. For the output flow, another MLR was carried out but using as a dependent variable the percentage of portability and the thickness instead of the radius as the independent variable. Tables 9.9 and 9.10 show the data generated through the multiple linear regression (see Eqs. 9.1 and 9.2).

The data shown in Tables 9.9 and 9.10 were experimentally obtained when analyzing different umbrellas and with that, making a relationship between the variables. To get the percentages of length, radius, and thickness, it was necessary to divide each of these data between a maximum value to have dimensionless data that

Table 9.8 Forrester diagram nomenclature

Variable	Nomenclature
Level	
Flow	
Auxiliary	

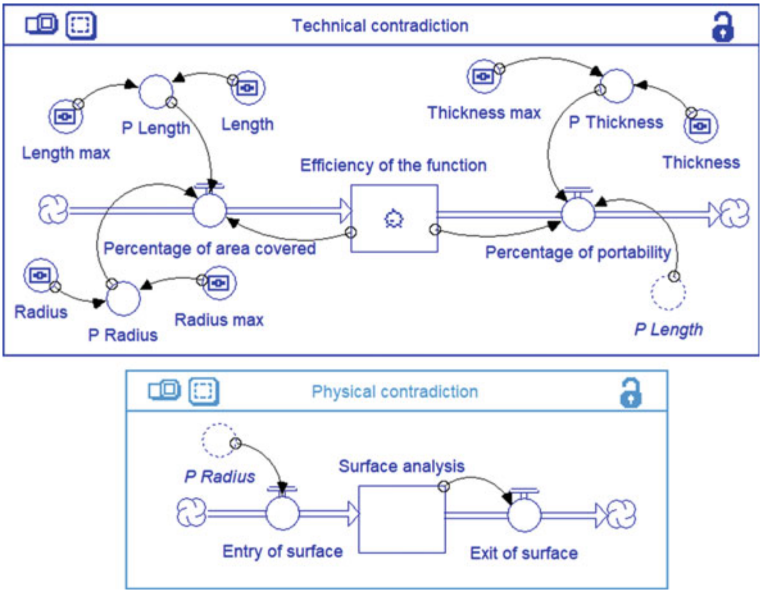


Fig. 9.9 Forrester diagram

Table 9.9 Multiple linear regression of area percentage

P. area covered (Y)	Efficiency of function (x_1)	Length (cm)	P. length (x_2)	Radius (cm)	P. radius (x_3)
0	0.00	0	0.00	0	0.00
0. 1	0.05	27	0.14	12	0.11
0. 2	0.11	43	0.22	23	0.22
0. 3	0.25	56	0.28	33	0.31
0. 4	0.37	88	0.44	37	0.35
0. 5	0.42	92	0.46	48	0.46
0. 6	0.70	132	0.66	52	0.50
0. 7	0.83	160	0.80	56	0.53
0. 8	0.90	178	0.89	69	0.66
0. 9	0.95	187	0.94	72	0.69
1	1.00	194	0.97	100	0.95

generate percentages. It was taken as maximum length = 200 cm, maximum radius = 105 cm and maximum thickness = 15 cm.

The equations that represent the flows are:

Input flow:

Table 9.10 Multiple linear regression of portability percentage

P. portability (Y)	Efficiency of function (x_1)	Length (cm)	P. length (x_2)	Thickness (cm)	P. thickness (x_3)
0	1.00	197	0.99	14. 5	0.97
0. 1	0.92	184	0.92	13. 6	0.91
0. 2	0.90	150	0.75	12	0.80
0. 3	0.88	130	0.65	9. 5	0.63
0. 4	0.80	102	0.51	6	0.40
0. 5	0.73	54	0.27	4. 5	0.30
0. 6	0.62	42	0.21	3	0.20
0. 7	0.50	20	0.10	2. 5	0.17
0. 8	0.47	15	0.08	1	0.07
0. 9	0.35	10	0.05	0. 8	0.05
1	0.00	0	0.00	0	0.00

$$P_s = -0.00868024 + 0.1374997E_f + 0.4270916P_l + 0.49310456P_r \quad (9.1)$$

Output flow:

$$P_p = 1.02717786 - 0.45576278E_f - 0.23704994P_l - 0.32485273P_t \quad (9.2)$$

where:

P_s Percentage of area covered
E_f Efficiency of function
P_l Percentage of length
P_r Percentage of radius
P_P Percentage of portability
P_t Percentage of thickness

The FD that analyzes the physical contradiction involves other equations. The equations that represent the flows are:

Input flow:

$$I_s = \pi(P_r)^2 \quad (9.3)$$

Output flow:

$$O_s = S_a \quad (9.4)$$

where:

P_r Percentage of radius

I_s Input parameters
O_s Output parameters
S_a Surface analysis

Stella© automatically generates the differential equations that represent the system that is being programmed, either in its differential form or its antiderivative form. Equations 9.5 and 9.6 represent the level variables of the FD (Fig. 9.9).

The differential equation for the technical contradiction

$$\frac{d(E_f)}{dt} = P_s - P_p \Rightarrow E_f(t) = E_f(t_0) + \int_0^t \left(P_s - P_p\right)dt \tag{9.5}$$

The differential equation for the physical contradiction

$$\frac{d(S_a)}{dt} = O_s - I_s \Rightarrow S_a(t) = S_a(t_0) + \int_0^t (O_s - I_s)dt \tag{9.6}$$

This contradiction requires two mutually exclusive states to generate a result. So, it is necessary to make a variation regarding the radius of the behavior of the system. The first situation involves increasing the percentage of radius (P_r). As a result, the effect produces an ascending graph that allows analyzing the increase of the function over time (Fig. 9.10).

Similarly, if the percentage of radius (P_r) decreases, a similar but descending graph emerges (Fig. 9.11).

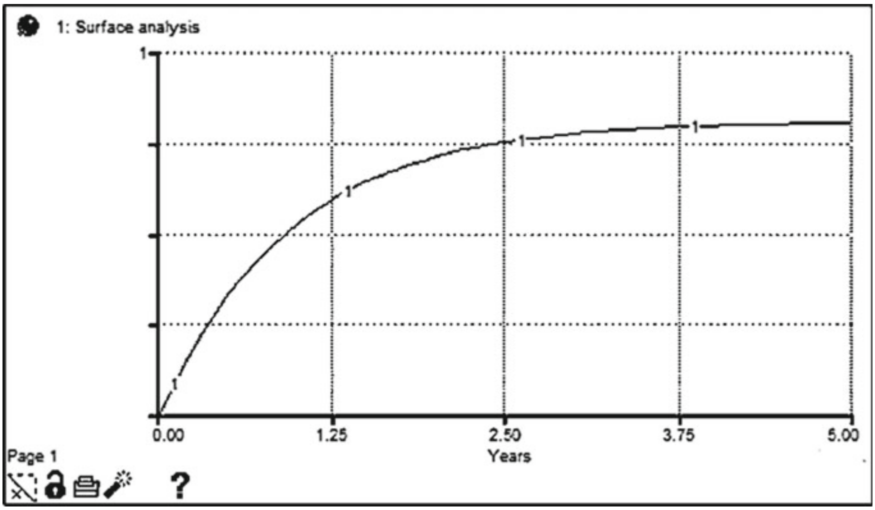


Fig. 9.10 Increasing the area

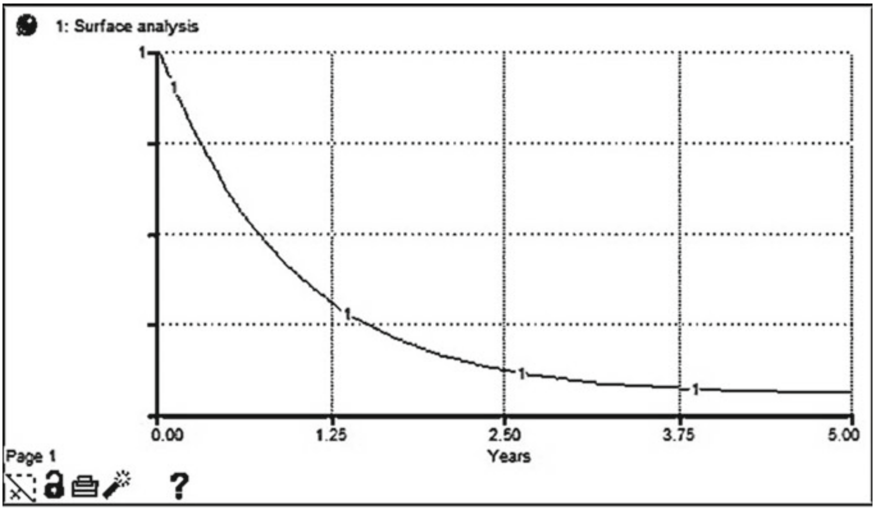


Fig. 9.11 Decreasing the area

Additionally, to the value of the radius percentage (P_r), it is also necessary to define the output flow value, which includes zero. The model (see Eqs. 9.4 and 9.6) requires a value essential of (S_a) to generate the corresponding graphs.

The contradiction arises when an increase in the variables of the inflow (P_s) generates a decrease in the variables of the outflow (P_p). These increases or decreases generate dynamic hypotheses:

(1) Increasing the area of the object produces less portability.
(2) Increasing the volume of the object produces greater efficiency.

Figure 9.12 shows the increase in the efficiency of the function when the input flow (percentage of area (P_s)) is tested with the output flow (percentage of portability (P_p)), generating the analysis of two loops simultaneously.

The CLD (Fig. 9.6) has causal relationships with positive or negative polarity. The two causal relationships, represented by the loops, are those that generate the contradictions mentioned in Sect. 9.4.1 (Fig. 9.6). The user can test the causal relationships by observing the logical increase or decrease of the variables according to what is expressed in the causal diagram. However, to verify this condition in the model, it is necessary to carry out some simulations to validate the causal relationships. In this step, the user can test the dynamic hypothesis in the model.

After the verification of the causal relationships, the user can perform some simulations by testing the model in different scenarios. Figures 9.13 and 9.14 show an example of different scenarios, when changing the variables shown in Fig. 9.2 (Thickness, radius, and length). Figure 9.13 shows the model simulation using values of $L = 95$ cm, $r = 85$ cm and $T = 8$ cm.

Changing the values of $L = 70$ cm, $r = 50$ cm and $T = 4$ cm, the resulting graph is.

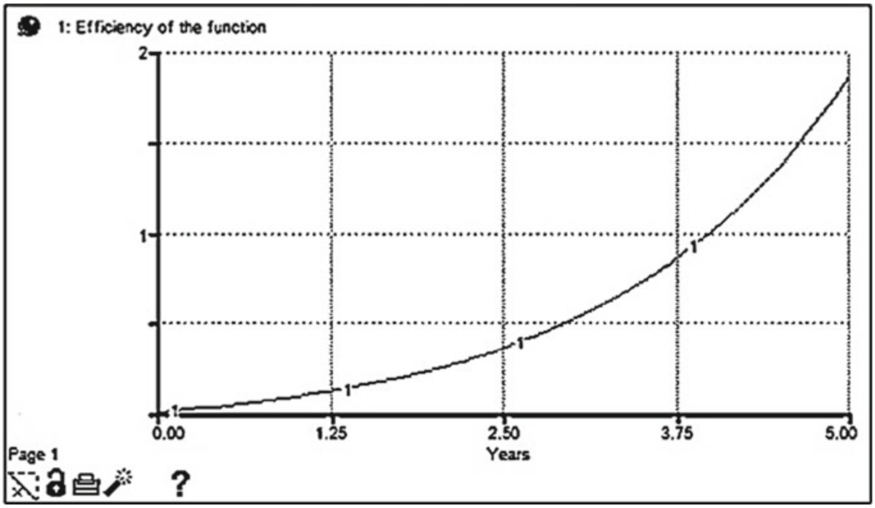


Fig. 9.12 Analysis of the efficiency of the function

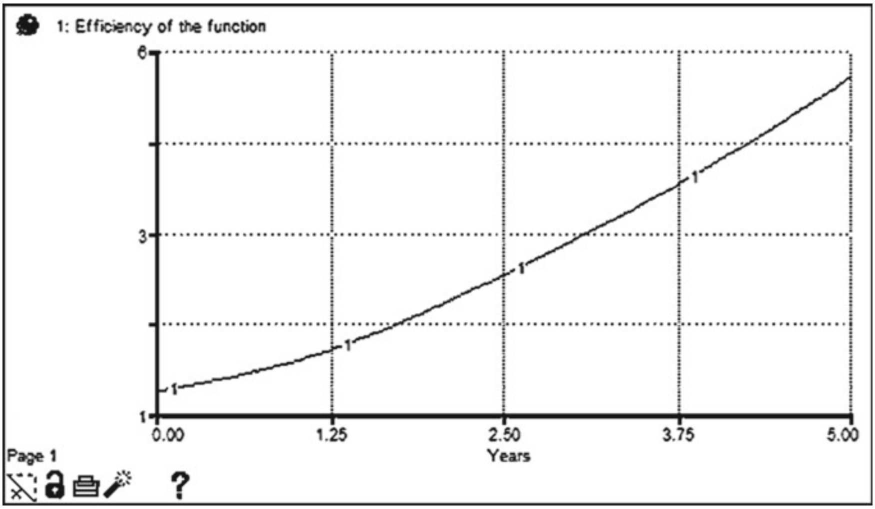


Fig. 9.13 First scenario

According to Figs. 9.13 and 9.14, when the user modifies the input variables, the simulation model produces a graph that reflects some effects. This information enables the user with new resources to evaluate a potential result. This process is the object of a more detailed analysis in the next section.

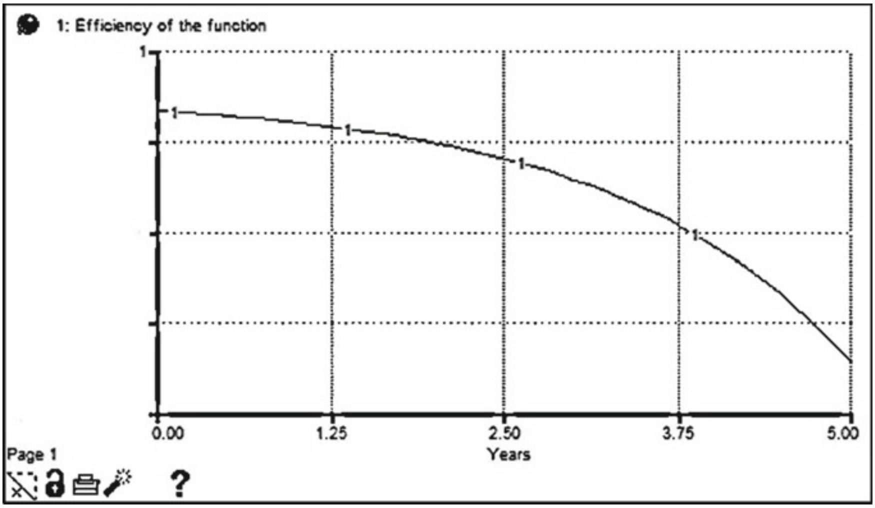


Fig. 9.14 Second scenario

With the information of different scenarios, the user will have a broader perspective on the impact that each variable has on the system. Hence, the user can document the results and classify them according to the sensitivity of the model.

Stella© allows the creation of an interface to analyze the programmed model and deliver an easy-to-operate model to the end user. Figure 9.15 shows the interface created for the simulation model.

From the interface, the end user can manipulate the input variables to observe the behavior of the programmed model according to the data captured.

Finally, the user can apply the contradiction matrix or the separation principles to propose potential solutions and then to perform various simulations. The interface allows the analysis of the object to see the proposed design improvements. After a certain amount of simulations, the user can identify future physical or technical contradictions.

The implementation of the simulation allows the user to analyze the behavior of the variables through a graphical interface to observe the effect of a potential solution. Next section offers an example of this process through the analysis of physical and technical contradiction, and the generation of potential solutions to an inventive problem and the simulation of some scenarios.

9.5 Discussion and Results

This section describes some potential solutions to the case study presented in Sect. 9.4. It shows a series of simulations that graphically analyze the behavior of the system using different input values. The information produced in the case

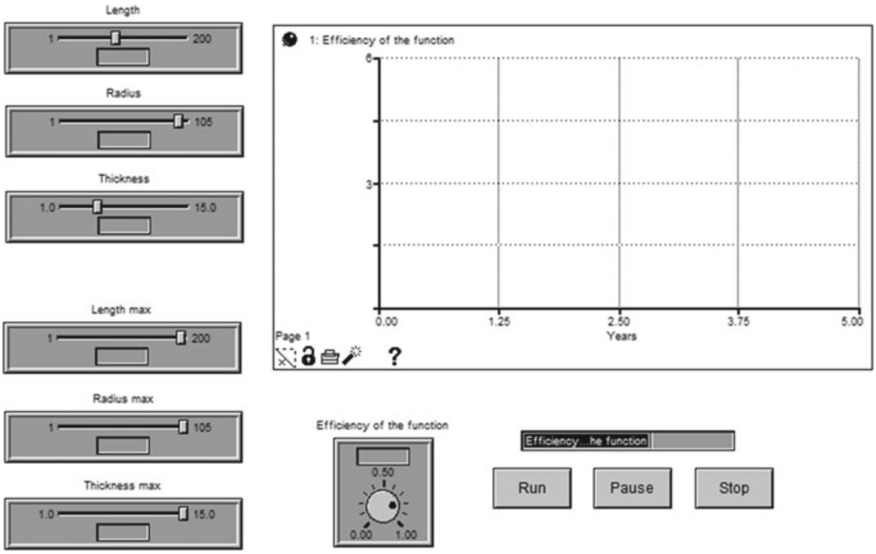


Fig. 9.15 Simulation interface

study allows to propose several conceptual designs, but only two are included in this section, and the SD explores the structural causes that affect the behavior of the system. This analysis increases the knowledge of the effects that each element has in the system and puts into evidence the most relevant relations to model and solve a problem. In the context of this framework, the presence of an inventive problem increases the system complexity. This condition is not related to the number of variables, but to the nature of the conflicts, the number of conflicts, and to the quality of proposed solutions (Savransky 2000). SD is the appropriated technique to deal with these conflicts, allowing the user to develop a strategy for solving inventive conflicts through a simulation model.

Figure 9.1 guides the formulation, analysis, and solving process of physical and technical contradictions through the application of SD. The case study shows that TRIZ and SD form useful tools where one complements the other. The need to create new knowledge to achieve the effective resolution of an inventive problem (Altshuller 1984) is the main argument to apply SD to TRIZ, but also due to the fact that SD does not have a tool capable of resolving conflicts. Then, it requires support from another technique and TRIZ is an alternative that has proven its effectiveness in different technological domains. On the other hand, TRIZ does not have a tool capable of mathematically modeling the conflicts that it faces. Perhaps, the main TRIZ limitation is that it deals with only one problem at a time. It is unable to solve or evaluate simultaneous conflicts. Hence, a conflict is considered as an independent situation, and consequently, it is not possible to assess what is the impact that one solution will have in the system. Additionally, the tools of TRIZ do not assist the user in the analytical stage of the problem as the selection of the right conflict, the correct solving principle or the most useful resource. This limitation implies low mathematical support in the use of TRIZ (Savransky 2000). As a result, the TRIZ drawbacks hinder the ability to solve problems in dynamic systems; thus the implementation of SD to TRIZ is a research opportunity.

This implementation enables the construction of an interface in the simulation model. It allows analyzing the physical and technical contradictions of the object being analyzed. The manipulation of the input variables (Thickness, radius and, length) through the interface generates different graphs of the behavior of the object in time. Figure 9.16 shows the graphic representation of a technical contradiction. As one variable increases, the other decreases. This analysis allows the user to make a visual analysis of the behavior of the contradictions.

This graph contributes to the analysis of technical contradictions and shows the relation between TRIZ and SD since it allows to analyze in time the behavior of the variables immersed in the problem-solving process of TRIZ. When examining the behavior of the graphs generated in SD, (Sterman 2000) states that there are some defined archetypes to study the system from these. The main archetypes (Fig. 9.17) reflect the growth or decrease generated from the feedback (R) or balancing loops (B).

The archetypes that adapt to the behavior of the presented case are exponential growth and goal seeking although the other archetypes can be presented depending on the value of the initial conditions. The archetype is useful for interpreting contradictions. Figure 9.17 shows an example of the behavior of the variables, through the exponential growth and goal seeking archetypes.

The case study shows a model that provides two useful functions: the ability to standardize the dimensional units and the use of the AHP to rank loops. Linear and

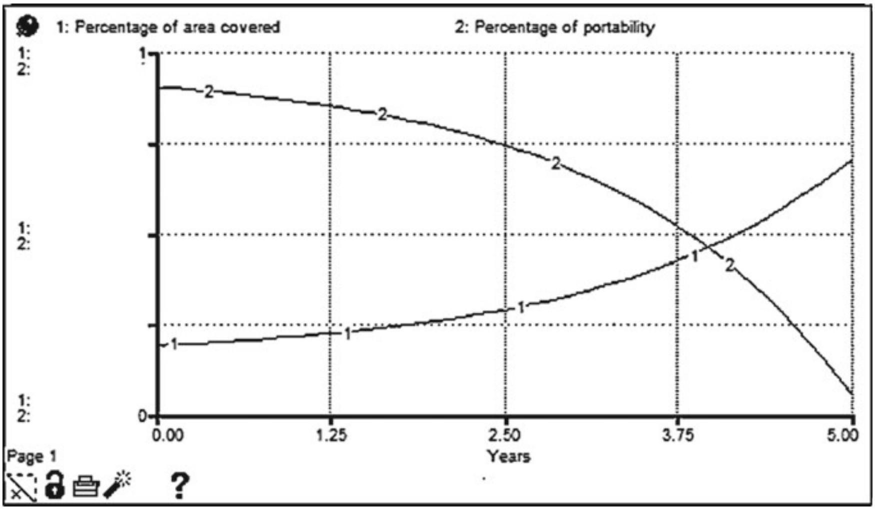


Fig. 9.16 Graphic analysis of technical contradiction

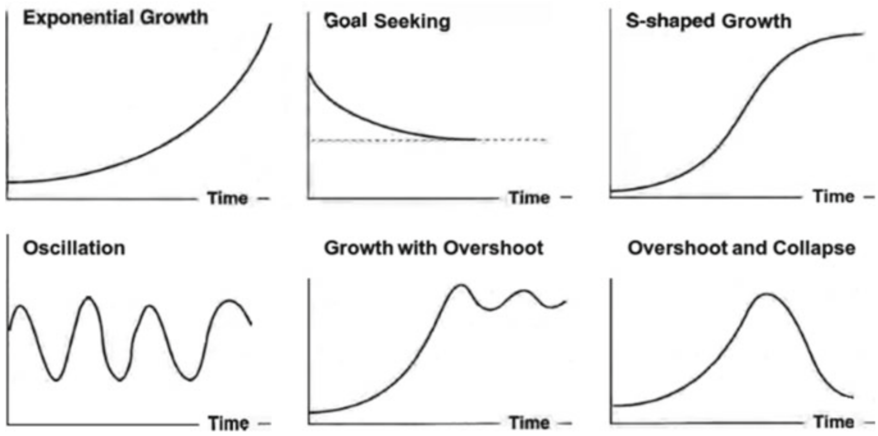


Fig. 9.17 Archetypes in SD (Sterman 2000)

square meters represent the unit of area, radius, thickness, and length. However, the dimensional representation of portability or efficiency does not have physical units, and it is dimensionless.

The lack of homogeneity between the dimensions produces a problem in Stella's programming. The conversion of the variables of Fig. 9.2 to dimensionless units through a mathematical quotient allowed solving the dimensional problem (Tables 9.9 and 9.10) (Matuszak 2015). With this process, all the units ended up being dimensionless. Further, the use of AHP within the methodology allows the user the ability to decide which loop has the highest priority in its solution, since currently, SD does not have a tool that allows hierarchizing problems.

9.5.1 Case of Study

The case of study comprises the application of the methodology created to solve physical and technical contradictions based on the input values that the user enters. Once the model is built, the user can enter the desired parameters to analyze the behavior of the system.

An umbrella has the following input parameters (see Fig. 9.2): $L = 90$ cm, $r = 75$ cm and $T = 6$ cm, it is considered that the current efficiency of the object is 80%. The maximum design values allowed in the simulation model are those described above ($L = 2$ m, $r = 1.05$ m and $T = 0.15$ m). The interface allows analyzing the physical and technical contradictions to explore the effect of a potential solution in the system.

9.5.1.1 Technical Contradiction Analysis

The user enters the previous values in the interface (Fig. 9.15) with a simulation period of five years. Figure 9.18 shows the resulting graph.

The archetype (Fig. 9.17) that adapts to the behavior in Fig. 9.18 is an exponential growth that increases year after year. Stella© allows placing in the interface a numeric display (see Fig. 9.19) that allows the user to know the final value of some variable of interest at the end of the simulation.

The efficiency measurement scale is dimensionless because it corresponds to a percentage. The value shown in Fig. 9.19 indicates the efficiency of the function. It is 4.37 and arises from the sum of efficiencies taking into account the time elapsed. Because the simulation period is five years, the user can get an average annual value. The above implies an increase in efficiency regarding the data initially entered (value originally entered = 0.80). When performing the operation of 4.37/5, it results in an average efficiency of 0.874, which includes the feedback loops (R) and the balance (B) that produce the technical contradiction.

According to the methodology in Sect. 9.3 to solve technical contradictions, it is necessary to use the contradiction matrix. The intersection of cells (volume of a moving object and the area of a moving object) recommends using the principles

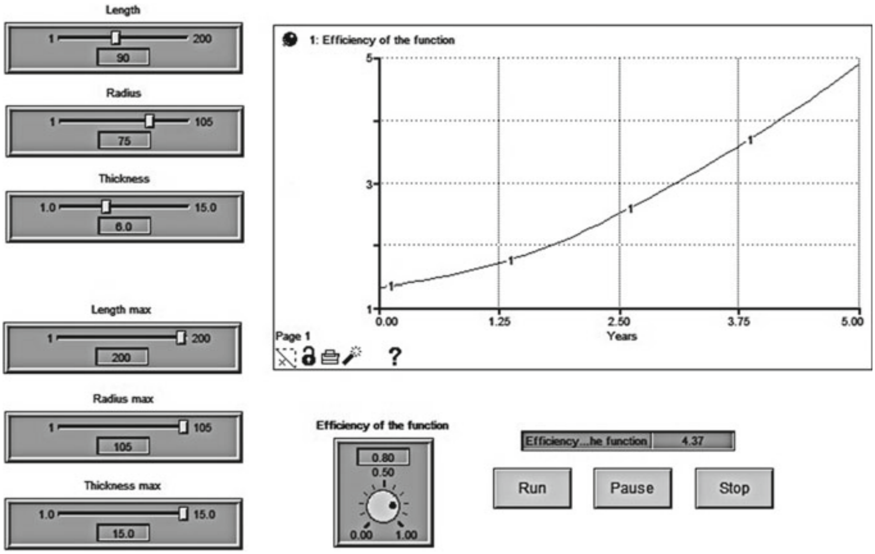


Fig. 9.18 First simulation for technical contradiction

Fig. 9.19 Numeric display

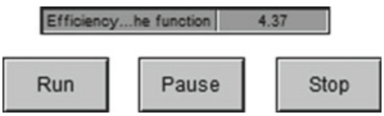


Fig. 9.20 Rib segmentation

of 17: another dimension, 4: change of symmetry, 7: nesting, 1: segmentation, 31: porous materials and 5: merging. They are applicable to solve the contradiction of the case study (volume vs area). The interpretation of the inventive principles shows that principles 1 and 7 (segmentation and nesting) are capable of solving the technical contradiction, due to its relationship with the dimensions of the object.

Currently, the segmentation of the ribs (using rivet and stretcher) has solved the problem of increasing the area covered by the object and taking care of its portability (Fig. 9.20). Consequently, this decreases the volume of the object when it is not in operation.

When applying the segmentation of the ribs, the original dimensions of the object undergo modifications. When performing a new simulation taking into account the segmentation, the new dimensions are: $L = 100$ cm, $r = 85$ cm and $T = 4$ cm. The above measures are proposed by the user. However, there are some examples of umbrellas with similar characteristics (see US7913709B2 and US7775226B2). Figure 9.21 shows the new graph and the new value in the numeric display.

With the new input variables, the sum of efficiency increased to 4.84 (Fig. 9.21), so that when dividing between the five years of the simulation, it is got that 4.84/5 results in an average function efficiency of 0.968. This factor shows that the new dimensions got from the TRIZ principles and available resources in the system increase the efficiency of the object when fulfilling its function.

9.5.1.2 Physical Contradiction Analysis

The simulation also allows an analysis of the physical contradiction, allowing the user to compare the parameter of interest against himself. For the case study, the parameter that originates the physical contradiction of area versus area is the radius. This parameter triggers the conflict.

In this analysis, it is only necessary to enter the radius of the object on the interface and the initial value of efficiency of the umbrella surface (S_a) described in the differential Eq. 9.6. Assuming that the initial conditions are $r = 100$ cm and current efficiency value of $S_a = 0.5$ (50%) yields the graph and the sum of the efficiencies with a time horizon of 5 years (Fig. 9.22).

The value provided by the simulation is 2.85 (Fig. 9.22), using the same procedure of the technical contradiction the result is 2.84/5 = 0.57. Also, it can be noticed that

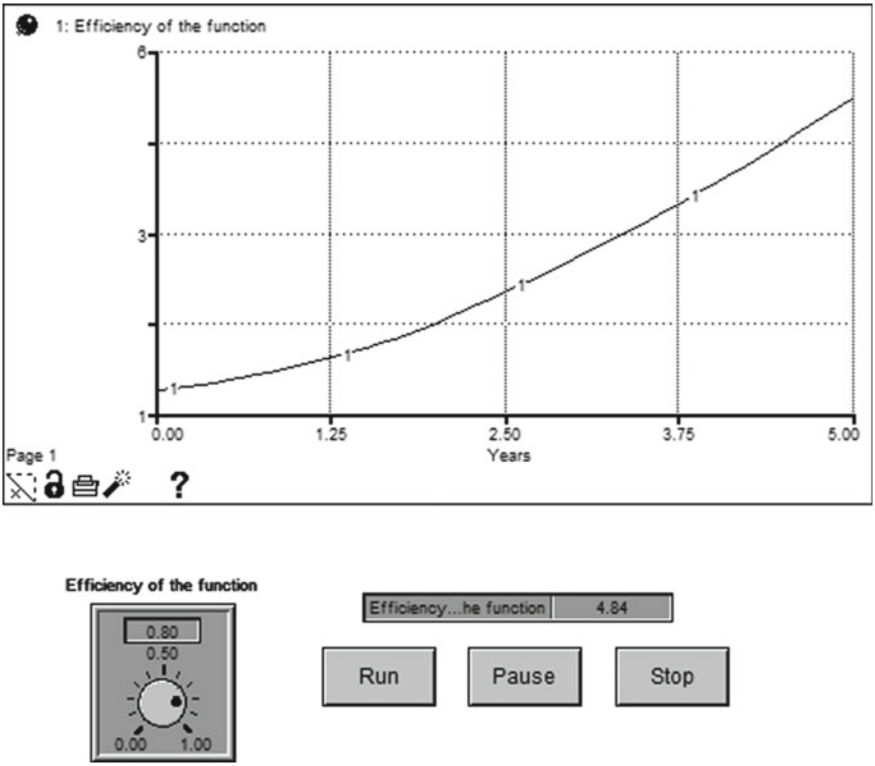


Fig. 9.21 Second simulation for technical contradiction

the originated curve grows in time showing that a higher radius contributes to an increase in the function. Nevertheless, any increase in the radius has other effects in the system, and it is in this collateral impact where the contradiction lies.

It was mentioned that the separation principles guide the process for solving physical contradictions. In the case study, the separation principle in time fits into the analysis of the contradiction, since the object must have certain dimensions while fulfilling its function and other distinct when it is not in operation.

If the user decreases the radius, the graph will have a significant downward change, and the value of the final efficiency will decrease. If the graph decreases to its lower value, it does not imply that the object is unusable, but only reflects that its function is not being carried out because it is not in operation. And therefore, the value of efficiency tends to be zero.

Assuming that $r = 10$ cm and current efficiency value of $S_a = 0.5$ (50%) the graph got the sum of the efficiencies with a time horizon of 5 years (Fig. 9.23).

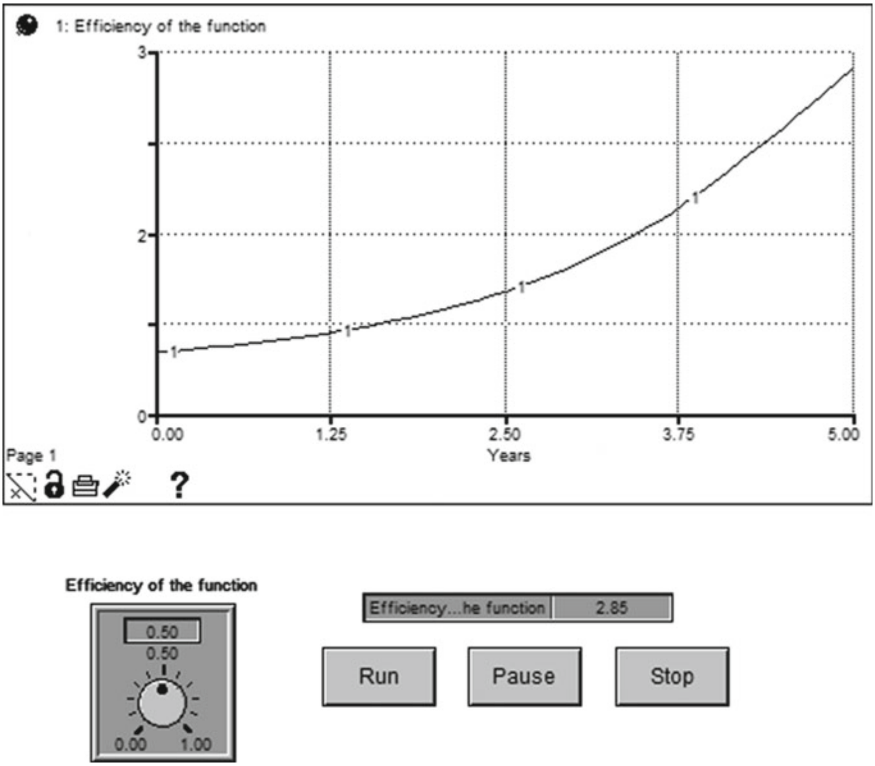


Fig. 9.22 First simulation for physical contradiction

9.5.2 Proposing Solutions

Once analyzed the physical and technical contradictions, the user has the SD approach to compare over time from the original design of the object. This vision allows the user to establish some future policies in the design of the object and make modifications to identify future contradictions.

Taking into account the separation principles in time, the inventive principles suggested by the contradiction matrix (nesting and segmentation), the use of resources and the application of scientific effects, the following design of the object is proposed.

An umbrella has the dimensions of $L = 90$ cm, $r = 85$ cm and $T = 5$ cm (some similar designs are available in patents US7484516B1 and US6311707B1). These measures are efficient since the value got in the numeric display is 4.69 (it arises from the sum of efficiencies in a period), giving an average efficiency of $4.69/5 = 0.938$ in a period of five years. However, the result is not adequate when the object will be used by two individuals instead of just one. To solve the problem, it is necessary to change the original design variables using the nesting (to solve the technical contradiction).

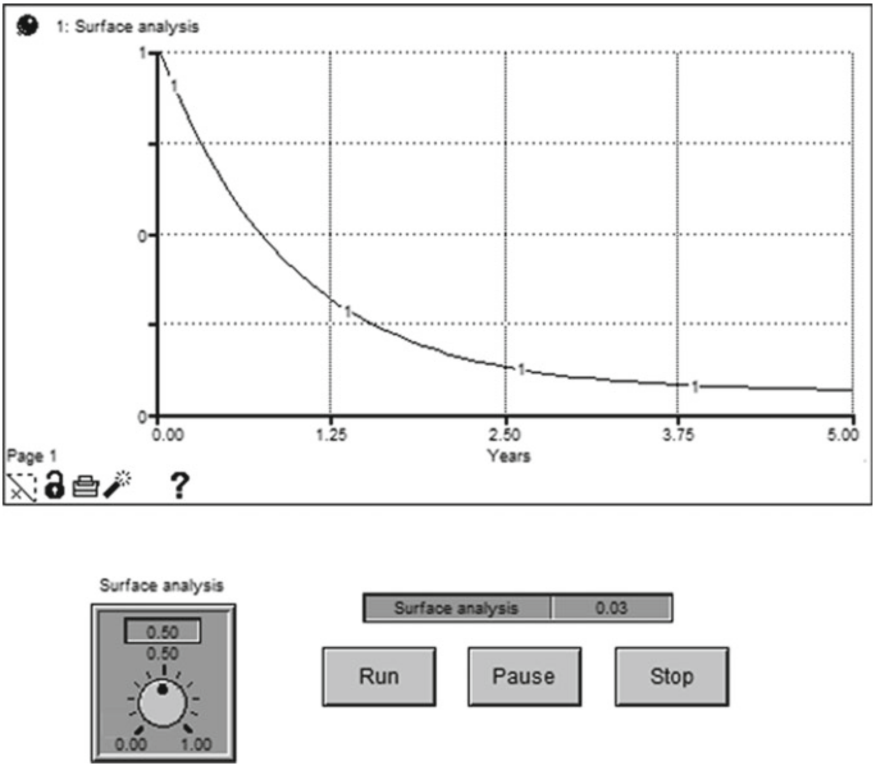


Fig. 9.23 Second simulation for physical contradiction

The inventive principle of nesting is based on the concept of the Russian Matrushka dolls. The above comprises placing an object inside another making the analogy of a telescope. Some products such as portable radios have applied this principle. According to Fig. 9.7 (Sect. 9.4.2.2) a typical umbrella uses the principle of separation in time because at one moment in time its radius is small and in another it is large. According to Sect. 9.4.2.1, one of the available resources is the use of surrounding areas. This is the suggestion that can be used to try to reach the ideal system. The ends of the ribs can be nested as with the pole and upper pole (Fig. 9.3). This concept corresponds also with the separation principle in time: The object from one moment to another can be deployed to increase its radius and fulfill the new function of covering two individuals simultaneously (Fig. 9.24).

The instant that the ends of the umbrella deploy, the radius will have a significant increase. The length and thickness dimensions will not change. A proposal for new measures is $L = 90$ cm, $r = 100$ cm and $T = 5$ cm (some similar designs are available in patents US6053188A and US5305771A). Due to the large dimensions correspond to a practically static umbrella. The new simulation results in the numeric display of 5.34 (Fig. 9.25), which when done in the 5-year period gives a quotient of 1.06,

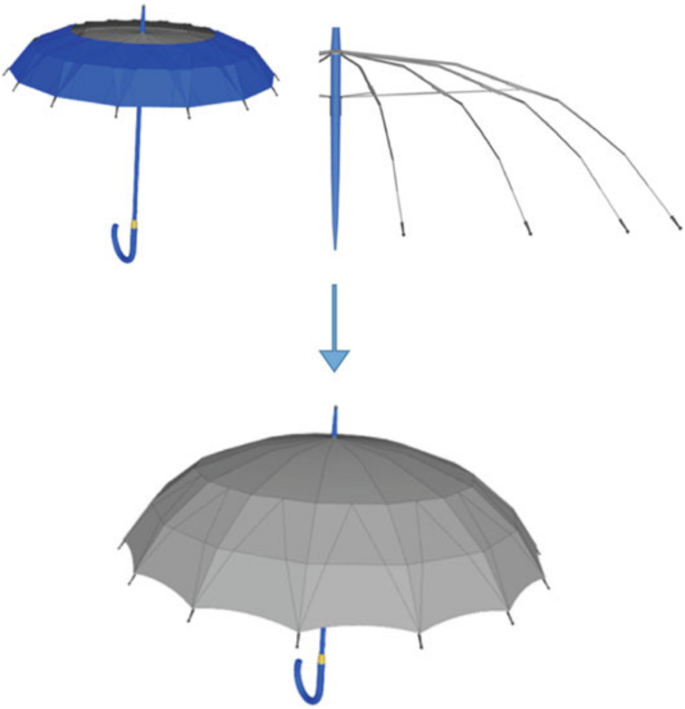


Fig. 9.24 First proposal design

which is higher than the previous one. This value shows the efficiency of using the separation principle over time or the inventive principle of Altshuller nesting combined with the SD approach.

The conceptual design proposes to independently use the surrounding areas. The solution increases the asymmetry of the object but provides the user with the capacity to expend the umbrella only where it is necessary (Fig. 9.26).

Using the measures $L = 88$ cm, $r = 105$ cm and $T = 5.2$ cm, the new result in the numeric display is 5.52 giving a quotient of 1.104 in the period established of 5 years (Fig. 9.27).

Table 9.11 shows a comparison between both conceptual designs. This includes the different values and the final quotient.

The efficiency before the design proposals was 0.968 (see Sect. 9.5.1.1). According to Table 9.11, the first conceptual design originated a quotient of 1.06 and the second 1.10. Both conceptual designs have more efficiency when compared to the original design proposal. A simple strategy to compare the initial state with the proposal is to use a mathematical percentage. Table 9.12 shows the comparison between conceptual designs.

From a summary, as presented in Table 9.12, the user can make decisions about different design proposals.

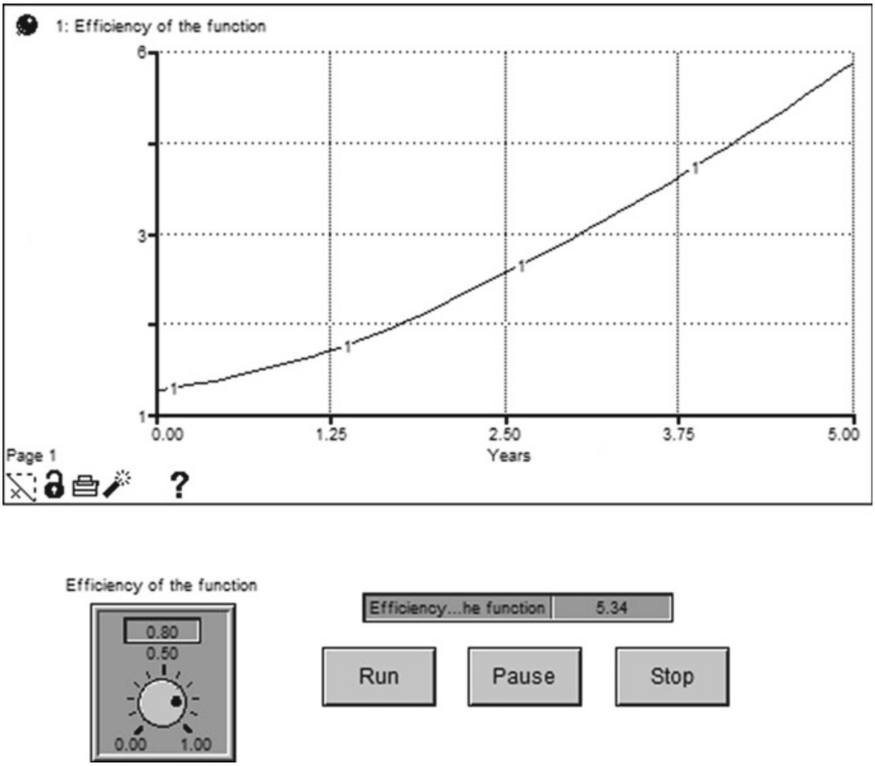


Fig. 9.25 First proposal solution

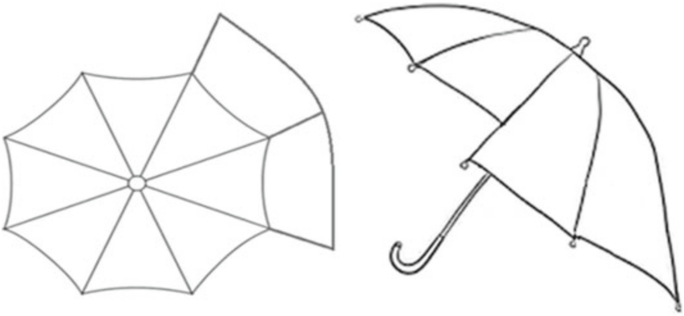


Fig. 9.26 Second proposal design

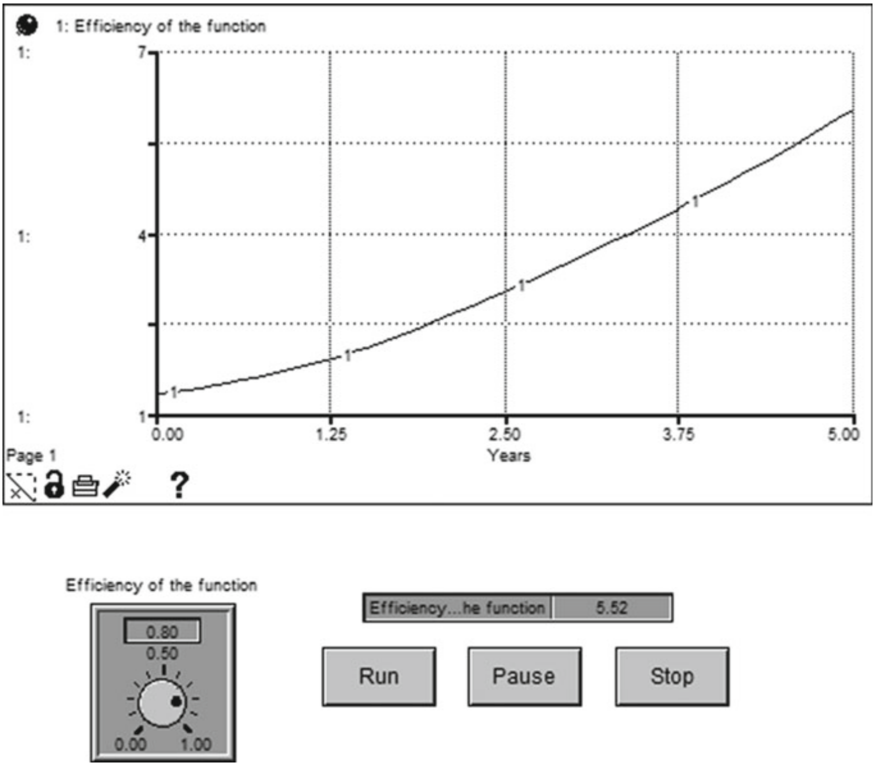


Fig. 9.27 Second proposal solution

Table 9.11 Comparison between conceptual designs

Conceptual design	Thickness	Radio	Length	Efficiency	Quotient
1	90	100	5	5.34	1.06
2	88	105	5. 2	5.52	1.10

Table 9.12 Improvement percentage

Conceptual design	Efficiency	Quotient	Original quotient	Operations	Improvement percentage (%)
1	5.34	1.06	0.968	(1.06–0.968)/1.06 = 0.08	8
2	5.52	1.10	0.968	(1.10–0.968)/1.10 = 0.12	12

Finally, it is important to underline that a comparison among available commercial TRIZ and SD software with the central approach of this framework is not an easy task. The reason behind this difficulty, are the functions that each software offers. Table 9.13 depicts the final evaluation of the approach according to commercial software. Next points briefly explore the advantages of each software:

- Goldfire Innovator is A IHS software. This is the most solid software platform for inventive problem-solving. It offers an extended set of functionalities classified as: analyze a market, develop a new product, improve a system, risk management and leverage intellectual property. Inside each class, there are different alternatives for deploying the software resources. This software facilitates collaboration and social interaction among users.
- Innovation Suite from CREAX. This is a solid desk application. It offers a modular process for problem-solving with 12 different steps. Each module is independent, and the user can implement their personal methodology for solving inventive problems. It is not possible to collaborate inside this software.
- TRIZ Note Pro is a mobile application that offers information and some fundamental guidelines to solve technical and physical contradictions, a tool for building

Table 9.13 Software capabilities

	Software						
Advantage	Goldfire Innovator	Innovation Suite	TRIZ Note Pro	TRIZ X QMS	Vensim	Stella	TRIZ + SD
Focuses on inventive problems	X	X	X	X	–	–	X
Modeling over time	–	–	–	–	X	X	X
Use of simulation	–	–	–	–	X	X	X
Analysis of complex system	X	X	–	–	X	X	X
Based on differential equations	–	–	–	–	X	X	X
Application to innovation	X	X	X	–	X	X	X
Modeling functional analysis	X	X	–	–	–	–	X
Use of tools for problem-solving	X	X	X	X	–	–	X
Strong evaluation capabilities	X	–	–	–	X	X	X

basic Substance-Field models, and some examples of the TRIZ trends of evolution. It is a useful tool for introducing the user to the main TRIZ concepts.

- TRIZ X QMS is an application for mobile devices specifically designed for improving the creativity of managers and Quality practitioners, but in general for the management domain. The mobile application has a tool for solving physical and technical contradictions. It also has a brief description of the TRIZ trends of evolution. This piece of software is more educational. It is possible to solve problems but it only guides the reasoning process while it stores the most relevant data about a problem.
- Vensim is a software useful for modeling and simulating systems dynamically. The interface allows the creation of Forrester Diagrams and simulates the behavior of a system in a period. Its biggest advantage over other software is that it has the ability to graphically represent a Causal Loop Diagram.
- Stella is a software package used to model dynamic systems. The software proposes four areas of work: the creation of interfaces, representation of Forrester Diagrams, programming the model, and the automatic creation of differential equations. The software allows the export and import of data from Microsoft Excel© and the creation of exportable files with the interfaces created.

As a final remark, the proposed methodology TRIZ-SD provides some advantages that are not available in commercial software yet.

9.6 Conclusions and Future Work

This work addresses a relevant topic, which is also a scientific opportunity in the solution of inventive problems. Currently, TRIZ and SD are techniques that operate as independent approaches. However, applying SD to TRIZ produces a result with great advantages when implementing it. This framework describes a strategy to overcome some of the current TRIZ limits. The SD approach provides TRIZ with the ability to analyze systems over time through continuous simulation. In exchange, the SD approach acquires the ability to propose inventive solutions. The main objective of this work was to demonstrate that it is possible to apply SD for solving inventive problems and obtain in return new capabilities for problem-solving. This objective was achieved through the interaction between TRIZ and SD in an approach that suggests the use of some TRIZ tools and concepts (the analysis of contradictions, the use of resources, ideality concept, and effects) with the SD modeling capabilities (causal analysis, mathematical modeling, and simulation). These tools assist the user to propose some conceptual designs. This implementation represents a contribution that is illustrated through a case study. As a result, the case study shows that both techniques reinforce mutually their capacities. The investigation describes an analysis done with SD that allows solving technical and physical contradictions. The case study shows the effectiveness of the synergy between TRIZ and SD. The implementation of SD offers the user the possibility to explore the intrinsic relations within a system to decide what conflict is more important than other.

Also, this new approach enables the search for the solution to inventive problems with greater complexity. This case study offers the analysis of the feedback loops (R) and the balancing loops (B) that are part of the system. The feedback loop (area) is what causes the system to grow indefinitely, while the balancing loop limits the growth that can provide a decrease instead of an increase (Fig. 9.23). Once the model is generated, the user can propose different scenarios and to evaluate the impact that a design variable or parameter has on the system. The user explores various possibilities in the design process through an interface. With the implementation of Stella software, the user has the ability to graphically analyze the behavior of the system and carry out a feasible decision-making process. There are areas of opportunity to implement the methodology created: The implementation shown in this framework is useful to solve inventive problems in manufactured goods and services. However, the implementation of this new approach in the processes area entails an opportunity for improvement due to a large number of physical and technical contradictions immersed in a process.

This framework only covers the contradiction analysis of TRIZ and its integration with SD. However, both approaches can obtain greater benefits if they integrate other techniques. Future work suggests incorporating within the methodology the analysis of another tool of TRIZ: The Trends of Evolution (ToE). The application of ToE involves the study of patents and the analysis of significant changes in the designs of products and services, generating a considerable contribution to the methodology proposed in this work.

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