

## Article

# A Combined Use of TRIZ Methodology and Eco-Compass tool as a Sustainable Innovation Model

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**Abstract:** In recent years, there has been an increase in the adoption of quality tools by companies. As such, there has been a commitment to innovation by the organizations to obtain competitive advantages by the development of new products and technologies focused on the creation of economic value but also on delivering sustainability. This study aims to develop an application model of the inventive resolution theory in conjunction with the Eco-Compass ecological innovation tool, in order to allow solutions to be obtained systematically, and to present a performance increase of certain environmental parameters, promoting thus sustainable innovation. The case study research methodology is used to frame the research. The company under study is Nokia enterprise, located in Portugal, which offers a set of services related to telecommunications infrastructures. The unit of analysis is the department of transformation and continuous improvement, and the study illustrated the application of combined use of theory of inventive problem solving (TRIZ) and Eco-compass to develop innovative solutions systematically. The results show that it is possible to achieve innovation according to a certain level of established sustainable environmental parameters, while at the same time solving the identified inventive problem.

**Keywords:** TRIZ methodology; Eco-Compass; environmental impact assessment tool; eco-design; eco-innovation

## 1. Introduction

Currently, enterprises can use a diverse set of tools and methodologies to improve the performance of applied knowledge in organizations. Due to their ever-increasing adoption, the differentiating factor has become not only increased competitiveness through efficiency gains in their internal processes, but also the creation of new products that competition cannot offer [1].

The development of new technologies has thus taken an extremely important role in today's economic growth, but unfortunately, it has also assumed the same role in the unfolding of the current environmental crisis. When innovation is generated, economic aspects usually become more relevant in its design, and its environmental impact is neglected [2,3]. This mindset has recently changed, and companies and organizations are also increasingly adopting non-economic performance measures for their activities, such as using eco-design in order to achieve a positive environmental impact or sustainable performance of their products [4,5]. This is because a relationship has been detected between customer loyalty and a sustainability effort on the part of companies due to an increased

public perception of the impact of human beings on the environment, and the need to reduce or reverse it in order to minimize potential future environmental changes that could affect their lives [6].

In order to meet this growing need, new methodologies and tools have begun to be developed in the academic and business world with a focus on product design, taking into account their environmental impact [7]. Currently, many eco-design methods of new products are being combined with eco-innovation, and the reason is that it is in the design stage that lies the key factor of the product's environmental impact during its life cycle [8]. In this context, philosophies such as the theory of inventive problem solving (TRIZ) have gained relevance by allowing their users to access methods that enable them to solve difficult technical problems, and in need of consistent and structured creative solutions [9]. These characteristics disassociate the process of innovation or problem solving from the idea that they only occur in moments of inspiration, allowing for dynamic management and active planning [10]. Multinational companies such as Samsung, Ford, and Siemens have already shown positive results in the application of TRIZ, as well as small and medium-sized enterprises (SME) in Europe and the United States, demonstrating that there are advantages resulting from its use [11]. Employing TRIZ tools in eco-innovation design tasks have been proposed during the last 2 decades and has been widely employed in the primary stages of eco-design. New ways were identified in which TRIZ methodologies and tools could be utilized in eco-innovation [12].

However, there are limitations to the tools employed by TRIZ, and this topic is the subject of extensive academic and research work in finding combinations with other methodologies in order to bridge these limits [13]. This paper proposes to direct the application of this theory in order to generate solutions that meet certain pre-established values of sustainability parameters by combining their use with the Eco-Compass tool. The Eco-Compass tool [14] was developed with the purpose of evaluating the sustainability performance of products/services, being characterized as being intuitive to use, making it very relevant in the field of ecological innovation due to its popularity. This was created in order to summarize parameters associated with the sustainability theme of the product or service under analysis, in a simple model, so that it can make a comparative analysis of it with a base scenario. In this way, it is possible to make an assessment of the evolution of their design during their various stages of conception, in ecological terms, that is, eco-design [15]. This tool was selected due to its compatibility with the matrix of contradictions belonging to TRIZ, allowing to explore their joint application and the bridge that is created in order to overcome the limits that each of these tools present.

Several studies have addressed and linked TRIZ with sustainability in a wide range of areas and applications, from eco-innovation to social sustainability and ergonomics. In [16], the authors propose, in order to achieve more environmentally friendly and sustainable buildings, different possibilities to model green roofs related problems with distinct TRIZ tools. Eco-design has also been a topic of interest in which TRIZ tools are used to ensure that sustainable results are embed into everyday design practice [17], and these tools are used to assess if the value of existing solutions can be improved according to sustainability requirements. Additionally, regarding Eco-design, a TRIZ-based eco-design matrix was proposed in [18]. In another study and also regarding design, a tool that faces the absence of a common vision regarding sustainability during the first phases of design based on key items of TRIZ is proposed [19]. Quality function deployment (QFD) combined with TRIZ was used in several studies in order to achieve a sustainable design [20–23], while other authors call it environmentally conscious quality function deployment (ECQFD) [24]. A study proposes a sustainability planning platform through a balanced scorecard comprising of QFD, TRZ and abridged life cycle assessment (ALCA) [25].

Eco-innovation can also be fostered by TRIZ. The evaluation and application of the TRIZ methodology are proposed in [26] with the purpose of increasing eco-innovation in small and medium-sized enterprises (SMEs), and the authors concluded that by using TRIZ it is possible to achieve efficient and rapid processes, products, and sustainable services. In [27], a resource-constrained innovation method is proposed in order to produce ideas for new product development based on TRIZ.

Fomenting early eco-innovation design for products that integrate case-based reasoning and TRIZ method was addressed in [28].

TRIZ has also been used in conjunction with life-cycle assessment (LCA), and in a study the authors used a graphical ontology in order to guide the designer in mapping the product life cycle [29]. While in another study [30] these authors aim to integrate TRIZ derived eco-guidelines with LCA in order to obtain a sustainable design and process. In [31,32] the authors propose a reasoning model in order to achieve innovative ideas straightforwardly for designing eco products with simple LCA methods. This finding suggested that using TRIZ could be more helpful for mature products.

The link between TRIZ and social sustainability has also been a focus of study, and, for instance, TRIZ and the paradigms of social sustainability in product development are addressed in [33]. On that trend, the authors in [34] propose a conceptual integrative model of Kansei Engineering, Kano and TRIZ in order to foster sustainability in services in which healthcare is used as an example. Another study has considered these models and SERVQUAL by addressing ergonomics sustainability [35].

As can be seen, TRIZ is applied for a wide range of areas related to sustainability. All of these studies address TRIZ and its relation to sustainability. Even though many studies address the use of TRIZ in eco-innovation in many forms, no model of TRIZ with Eco-Compass has been proposed in the literature. Therefore, in order to bridge this gap, the objective of this study is to develop an application model of the inventive resolution theory in conjunction with the Eco-Compass ecological innovation tool, especially the compatibility between the Eco-Compass tools and contradiction matrix, in order to allow solutions to be obtained systematically, and to present a performance increase of certain environmental parameters, promoting thus sustainable innovation. A case study at Nokia enterprise is addressed in order to illustrate its functionality. The compatibility between the TRIZ and the Eco-Compass is studied, and a relationship between them is proposed by adapting the environmental goals to the engineering parameters. In a case study research setting, one application of the model is exposed and further analyzed, in order to validate the proposed model in a business and service context.

## 2. State-of-the-Art

TRIZ is known as the theory of inventive problem solving and was developed by Genrich S. Altshuller, and his colleagues became known in 1956 [36]. He realized that inventions, innovations and problem solutions could be systematized [37]. The basis for this realization was the evaluation of a total of 200,000 evaluated patents. In doing so, Altschuller realized that the inventions and innovations are subject to certain principles and patterns, which in turn means that they can be repeated and used for future problem solving [38]. Altshuller was able to reduce the engineering parameters present in contradictions to a 39-entry list. These were also set for both moving and static objects. Moving objects are objects that can easily change their spatial position, influenced by external or internal forces. Static objects do not change their spatial position. The 39-entry list of engineering parameters can be accessed in a published study [39]. In order to solve the contradictions made by the 39 engineering parameters, which are approximately 1250 contradictions, the 40 inventive principles are proposed, which are inventive solutions that are capable of solving contradictions [40]. Figure 1 illustrates the 39 engineering parameters and Figure 2 shows the 40 inventive principles.

1. Weight of moving object	14. Strength	27. Reliability
2. Weight of non-moving object	15. Durability of moving object	28. Accuracy of measurement
3. Length of moving object	16. Durability of non-moving object	29. Accuracy of manufacturing
4. Length of non-moving object	17. Temperature	30. Harmful factors acting on object
5. Area of moving object	18. Brightness	31. Harmful side effects
6. Area of non-moving object	19. Energy spent by moving object	32. Manufacturability
7. Volume of moving object	20. Energy spent by nonmoving object	33. Convenience of use
8. Volume of non-moving object	21. Power	34. Repairability
9. Speed	22. Waste of energy	35. Adaptability
10. Force	23. Waste of substance	36. Complexity of device
11. Tension, pressure	24. Loss of information	37. Complexity of control
12. Shape	25. Waste of time	38. Level of automation
13. Stability of object	26. Amount of substance	39. Productivity

Figure 1. The 39 engineering parameters.

1. Segmentation	11. Cushion in Advance	21. Rushing Through	31. Porous Material
2. Extraction (Extracting, Retrieving, Removing)	12. Equipotentiality	22. Convert Harm Into Benefit	32. Changing the Color
3. Local Quality	13. Do It in Reverse	23. Feedback	33. Homogeneity
4. Asymmetry	14. Spheroidality	24. Mediator	34. Rejecting and Regenerating Parts
5. Consolidation	15. Dynamicity	25. Self-service	35. Transformation of Properties
6. Universality	16. Partial or Excessive Action	26. Copying	36. Phase Transition
7. Nesting (One object is placed inside another)	17. Transition Into a New Dimension	27. Dispose	37. Thermal Expansion
8. Counterweight	18. Mechanical Vibration	28. Replacement of Mechanical System	38. Accelerated Oxidation
9. Prior Counteraction	19. Periodic Action	29. Pneumatic or Hydraulic Constructions	39. Inert Environment
10. Prior Action	20. Continuity of Useful Action	30. Flexible Membranes or Thin Films	40. Composite Materials

Figure 2. The 40 inventive principles.

After extensive analysis of this set of patents, Altshuller and his colleagues realized that only a small portion of these actually represented innovation by creating a conceptually new product from scratch. Moreover, they have found that most of the cases studied simply applied improvements to existing systems using solutions previously applied to other products or areas [41]. TRIZ was developed to provide the tools and methods necessary for the innovation process, allowing the user to obtain innovative solutions through their use [42]. Therefore, TRIZ aims to structure and introduce a methodology to the creative process of problem-solving in order to generate innovation, being especially indicated to be applied in engineering problems [43].

The analysis of the evolution pattern of innovation highlighted two very important aspects for TRIZ, which are the evolution of product/service design, and the existence of generic principles for innovation generation. Currently, TRIZ can be used to solve issues exposed in the form of characteristics or unwanted performance measures, for instance, consuming a high level of energy [44],

in order to exploit an existing system and detect and improve the performance of any detected problem, predict evolutionary system trends, identify future system iterations, anticipate potential future failures, act before they occur or build new systems from scratch [28].

TRIZ's general solution model introduces a methodology that allows the user to abstract a specific problem, work on it in its generic format, and apply the generic solution obtained in the context under analysis. The steps of the methodology initially consist of a system analysis and problem identification, translating them into an abstract problem format, using the various tools available in order to obtain a generic solution and then contextualizing the results in order to arrive at a specific solution of the problem [45]. This methodology allows the identification and reuse of known and registered concepts and solutions exposed to a high level of abstraction, accelerating the process of solving the inventive problem by reducing the effort required [46].

TRIZ can be considered as a set of tools, methods and/or philosophies, depending on the level to which it is observed or applied. TRIZ's philosophy is based on five key concepts, ideality, resources, functionality, contradictions, and space/time [47]. TRIZ has several tools that have been incorporated into it over time, through studies conducted by practitioners and/or in the academic field. However, the criteria for choosing the ones to use depend on each expert's personal preference and experience. To aid the experts [48] proposed a set of TRIZ tools to use due to their performance and popularity.

### *2.1. Contradictions Matrix*

This tool is one of the most popular within the body of TRIZ. Technical contradictions can be resolved using the 40 principles of the invention; these can be verified in a published study [39] and observed in Figure 2. This is the main tool of the TRIZ body, and their use is relatively intuitive and effective, having been obtained through extensive patent analysis initiated by Altshuller while observing the methods used to solve various genres of contradiction. These methods have been recorded, cataloged and generalized so that they can be interpreted according to the context presented, regardless of the field of science they are in [49].

In order to resolve a contradiction, it is first necessary to identify the problem in order to define the conflicting engineering parameters [50]. The matrix of contradictions can then be consulted by selecting the parameter to be improved from the horizontal lines and then looking for the intersection of that line with the respective column of the other identified parameter of the contradiction. Within each matrix cell, there are numbers that act as references to the principles to be used in case of a given contradiction [51].

### *2.2. Nine Windows Creativity Technique*

This technique consists of constructing a table with nine entries, separating in three categories: supersystem, system and subsystem in the separating three time periods—the past, present and future. Next, the cells have to be filled with descriptions corresponding to the present for the three system categories in order to contextualize the addressed problem under external and internal environments. After this step, the rest of the existing cells in the table need to be identified and filled in, allowing an analysis of its historical path, and any desired future progression [52].

Through the use of this exercise allows its users to identify and map the historical context of the problem, its needs, cause–effect relationships and resources needed both in time and for the system. Nine windows creativity technique also takes advantage of the opportunity to analyze the temporal evolution of the system's surroundings, and at the same time, compel a working group to define and reconcile any future perspectives for the system [52].

### *2.3. Resources Checklist*

The use of resources, in the context of TRIZ, refers to their actual use within and on the periphery of the system. This information gathering work, in order to identify potential available resources,

allows a better understanding of the system itself, while at the same time detecting possibilities for improvement [53].

#### 2.4. Ideality

A system increases in ideality the more beneficial functions or fewer harmful functions it has, the lower associated costs involved, and a lower manufacturing complexity required [54]. In the course of TRIZ problem solving, the concept of the optimal solution is defined as a goal to be achieved.

By defining what the ideal final result (IFR) of the problem is, the subject is forced to think about what goals must be achieved and what are the desired requirements in the obtained solution. Having a more specific orientation towards solving the problem can avoid any unnecessary efforts due to a misconception of the problem in question [53].

This concept is especially useful in situations where stakeholders are also involved in the problem-solving process by allowing them to make their own personal contributions in the process of defining the ideal system, clarifying their needs or wants, and giving them an opportunity. The group to define a consensus that pleases all parties [55]. IFR, by definition, should include all the benefits the customer wants, not produce waste or adverse effects and be able to be produced at zero cost [55]. This means that IFR is considered an ideal solution in a perfect world.

#### 2.5. Eco-Compass

Together with the utilized TRIZ tools, and in order to provide support to the working methodology applied throughout the work in order to obtain results taking into account the environmental impacts of the product/service, the Eco-compass tool was selected due to its eligibility and compatibility with the TRIZ body of knowledge [3].

There are plenty of tools that have been developed to provide methodological foundations in product and/or service design, such as the Life-cycle Design Strategy Wheel and Eco-Compass. These tools provide efficient assessment methods, using key environmental indicators, to compare a new product against a baseline scenario [14].

However, Eco-Compass presents itself as one of the most popular tools in the area of green innovation due to its level of usability, i.e., ease of use, which in the fast and competitive business context is an extremely important factor for adoption of these by business/corporate managers [56].

Eco-compass is a tool for evaluating eco-efficiency and for improving eco-innovation and was developed by Dow Europe. It has this name due to its distinguished design, which is in shape with six axes on a radar chart, where each represents an environmentally relevant variable: mass intensity, potential risk to human and environmental health, energy intensity, waste reuse, resource conservation and service/function longevity [57]. Using this tool is to set a base scenario by scoring each of the fields with a value of 2, and then evaluate the new scenario(s), giving each parameter a certain score for the set scenario [14].

#### 2.6. Triz + Eco-Compass

In order to define a connection between the Eco-Compass tool and the TRIZ body, a link between it and the contradiction matrix tool was explored by David Harrison [15], and it was revealed that each of the goals examined: mass intensity, potential risk to human health and environment, energy intensity, waste reuse, resource conservation and service/product longevity may be associated with certain engineering parameters defined by Altshuller. The proposed associations, adapted from a study [15], identified which of the 39 TRIZ parameters has a correlation with the Eco-compass variables. Table 1 shows this correspondence. However, some relationships were not fully identified, and these were revised for the scope of this work. Thus, new associations highlighting the synergies and similarities between the TRIZ engineering parameters and Eco-Compass variables are proposed as shown in Table 1.



**Table 1.** The 39 TRIZ engineering parameters and Eco-Compass variables.

Eco-Compass Variable	Association with 39 Engineering Parameters Proposed by [15]	Association with 39 Engineering Parameters Proposed in the Study
Mass intensity	1. Weight of moving object 2. Weight of non-moving object 23. Weight of substance 26. Amount of Substance 39. Productivity	1. Weight of moving object 2. Weight of non-moving object 23. Weight of substance 26. Amount of Substance 39. Productivity
Potential risk to human health and environment	31. Harmful side effects	22. Loss of energy 23. Loss of substance 31. Harmful side effects
Energy intensity	19. Energy spent by a moving object 20. Energy spent by a stationary object 22. Loss of energy 39. Productivity	19. Energy spent by a moving object 20. Energy spent by a stationary object 22. Loss of energy 39. Productivity
Waste Reuse	31. Harmful side effects	31. Harmful side effects
Resource Conservation	31. Harmful side effects	22. Loss of energy 23. Loss of substance 31. Harmful side effects
Service/Product Longevity	15. Duration of action of moving object 16. Duration of action of stationary object 27. Reliability 34. Repairability 35. Adaptability 39. Productivity	15. Duration of action of moving object 16. Duration of action of stationary object 27. Reliability 34. Repairability 35. Adaptability 39. Productivity

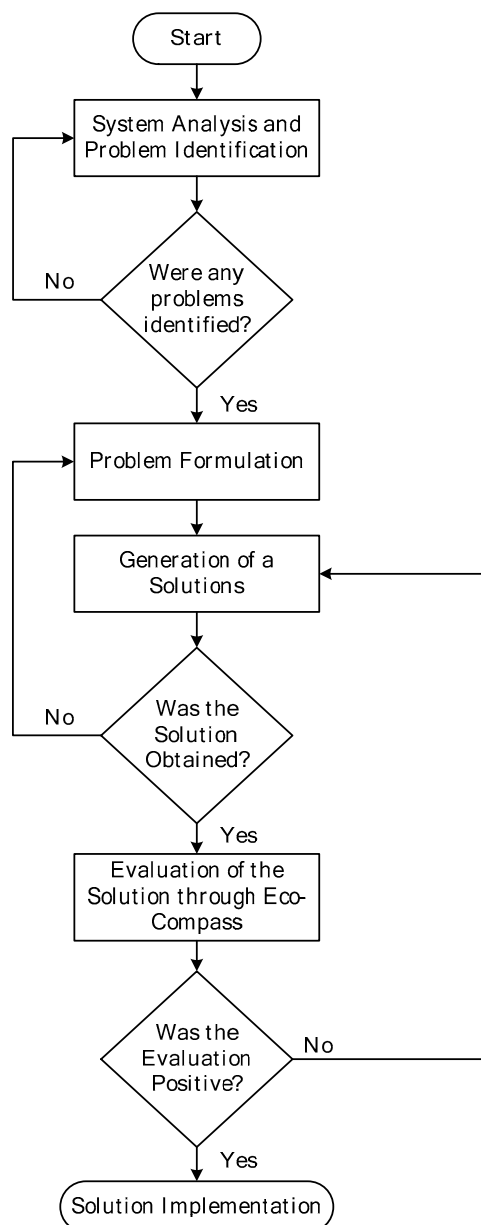
As can be seen from Table 1, in the joint application of these two tools, the Eco-Compass headers that represent the greatest difficulty in associating with TRIZ's 39 engineering parameters are the "potential risk to human and environmental health", "waste reuse" and "resource conservation", which initially were related to a single engineering parameter "harmful side effects" [15].

The review of potential new associations, developed for the purpose of the studies carried out, proposes to introduce the link between "potential risk to human and environmental health" and "energy loss", "mass loss" and "harmful side effects", assuming that waste of energy and/or mass may be related to inefficient systems, leading to a greater amount of energy or matter emitted without necessarily contributing to the desired effect, which may be harmful to the environment or human being, this risk translated by the parameter "harmful side effects".

It is also suggested to associate "resource conservation" with "energy loss", "mass loss" and "harmful side effects" as the phenomenon of waste reduction is usually associated with an efficiency gain, which in turn can imply a reduction of resources used. In this sense, and associated with the "harmful side effects" parameter, there is a need to reduce the use of resources that may generate the side effect.

### 3. TRIZ and Eco-Compass Model Proposal

This section presents the proposed model to integrate TRIZ and Eco-Compass with the objective of achieving innovation in view of its environmental impact. Taking into consideration the synergies and similarities between the Eco-Compass tools and contradiction matrix, the logic presented takes the form of the generic TRIZ use algorithm format, integrating the ecological tool as a quality control mechanism at the end of the solution generation process. In this way, it is possible to achieve innovation according to a certain level of established environmental parameters, while at the same time solving the inventive problem identified by maintaining the system functions. The flowchart of Figure 3 demonstrates the proposed model, and a brief explanation of each step will be performed.



**Figure 3.** The proposed model for the combined application of TRIZ and Eco-compass.

### 3.1. System Analysis and Problem Identification

In the course of system operation, various problems may occur, and some may be resolved spontaneously; others require/suggest innovative solutions. A problem survey is required at this stage, and dialogues with users who regularly interact with the system are recommended for a better understanding of the situation and the use of substance-field analysis to detect problematic elements or interactions. At this stage, it is recommended to apply the substance-field analysis tool and the ideality matrix.

The advantage of using substance-field analysis is the very methodology associated with its use, which is the analysis of the elements existing in the system and their interactions, in order to detect any harmful or incomplete interactions.

In the case of the ideality matrix, the work of defining parameters to improve in the system, and consequent identification of contradictions, allows the user to identify any obstacles to a certain desired evolution to the system.



If no problem is detected, it should be assumed that this is due to some omission from the analysis carried out, bearing in mind that it is extremely unlikely that there is no aspect or situation that could be changed or improved.

### *3.2. Problem Formulation*

After identifying the problem, following one of the TRIZ guides, it is important to formulate it correctly. If the problem is poorly defined, then the solutions generated to solve it will not be appropriate to observe the desired evolution of the system. In order to proceed correctly in this step, it is necessary to aggregate the results obtained from the previous steps, and to understand what the problem-solving approach will be, which will have a direct impact on the use of the tools employed in the future steps, and as such, on the results obtained.

### *3.3. Generation of Solutions*

Depending on the identified problem, physical or technical contradiction, TRIZ suggests the application of certain specific tools in order to obtain abstract solutions to be contextualized in the situation to be approached.

It is important to note that the user may not be limited to the proposed tools but is free to use tools with which he has more experience of use. This is due to the fact that it is recognized that in inventive problem-solving processes, there is a direct correlation between user experiences with given tools and the production of effective results through them. However, it is recommended to use Altshuller's 40 inventive principles in order to gain access to the database resulting from studies by TRIZ practitioners, allowing a pertinent focus on the available solution space, streamlining the problem-solving process.

It is also advisable to use the Nine windows creativity technique, making it possible to take advantage of the contextual analysis of the system, supersystem and subsystems in historical terms, and the definition of a concept of ideality for the system. It also helps setting a goal to be achieved through problem-solving and to structure requirements needed for eventual solutions. It is also suggested to use the substance-field analysis at this stage, in order to diagnose any undesirable or insufficient effects on the obtained solution, which can be complemented by applying the seven general solutions. Thus, it is possible to correct these interactions in advance before implementing them. If, from this step, any workable solution is obtained in the situation under consideration, then the assessment proceeds. Otherwise, a reformulation of the problem is necessary, allowing a new perspective on the situation.

### *3.4. Evaluation of the Solution Obtained with Eco-Compass*

In this step, the obtained solution is evaluated in terms of environmental parameters by comparing the obtained solution with the base scenario. Depending on the available information, this assessment can be made either qualitatively or quantitatively.

Recognition of the desired sustainability profile is required for the solution obtained, and this definition can be made in conjunction with the Stakeholders, or it can be framed with the environmental objectives stated by the responsible organization.

The result obtained can take several formats in terms of the profile presented. In situations where the profile obtained is within the established criteria, a reconfirmation of these is recommended to define whether the approved solution is to be considered or not. If it meets the requirements stipulated by the company/stakeholders, the final solution is approved. However, if this condition is not met, the engineering parameters associated with the failed environmental headers are identified, and a new application of TRIZ tools is required, and the subject will now be the proposed solution.

### *3.5. Reformulation or Creation of a New Solution*

A new problem is then identified, derived from the evaluation obtained by applying the Eco-Compass tool. The engineering parameters obtained from the association with its headers

are already identified, and it remains to be identified in which system or which components to act. For this purpose, the application of substance-field analysis is recommended.

After its identification, a reiteration of the solution generation phase is carried out, and its focus is already established through the substance-field model, starting with the construction of the ideality matrix, using certain engineering parameters already established and identified from the evaluation performed with the Eco-compass tool.

If no solution is obtained, it is necessary to re-examine the initially identified problem. However, if any solution is successfully obtained, a new evaluation using the environmental parameters is performed, keeping the initially contemplated scenario as a basis for comparison.

After the implementation of the obtained solution, it is recommended a new application of the Eco-compass tool in an operational context to evaluate it and to determine if there is any variability of results in terms of environmental parameters, as initially expected. This is recommended due to the fact that sometimes when deploying certain systems, it is necessary to make adjustments to unforeseen situations, and this may affect the expected performance of the solution.

#### 4. Research Methodology

A case study research methodology will be used to validate the proposed model for the combined application of TRIZ and Eco-compass and to illustrate his way of application. This research methodology is adequate when the boundaries of a phenomenon are not only still unclear, but there is also no control over behavioral events [58]. This is the case of the subject under study: using the TRIZ tools and Eco-Compass analysis as a means to promote innovation. Moreover, a case study method enables to develop a better insight into a complex and relatively unexplored phenomenon [59]. In particular, in the area of applied industrial technologies this research methodology as proven to be a valid way to study a vast range of topics such as assembly line design [60], product innovation [61], product service design [62] and business process analysis [63].

Case studies can be exploratory, descriptive or explanatory; they can be single or multiple case studies [59]. In this research, a single exploratory case study research design was selected. Since this research design focus just on a single case, a deeper study could be done, giving enough insights and better prospects to identify relevant issues [59,64]. However, a single case study research design has limitations related to the generalization of conclusions derived from the utilization of one case and the risk misjudging the representativeness of a single event, and of overstressing readily available data [64].

In this research, the case study was developed in the Nokia Company. The company is present on all continents and practically in every country in the world. With around 2000 employees in Portugal (Lisbon and Aveiro), Nokia is the market leader in equipment, solutions and services for mobile broadband networks. This company is focused on research and development so it can deliver the industry's an end-to-end portfolio of network equipment, software, services and licensing. The company's product portfolio consists of a set of services to be applied to telecommunications infrastructures.

The unit of analysis was the department of transformation and continuous improvement. During the course of the case study period, the company was in the process of restructuring, requiring an effort to gather information and map processes, but at the same time providing opportunities for transformation. Having made a survey of undesirable effects in the system, and determined in which elements it is intended to act, it is then necessary to make the formal formulation of the issue to be addressed. By crossing these two factors, the following statement guides the case study research: "What methodology to use for testing new work configurations, or tools, without disrupting the normal operations of project teams".

Two main research phases were planned to accomplish the case study objectives: phase 1—case study description, problem formulation, and generation of the solution and phase 2—evaluate the validity of the combined TRIZ and Eco-Compass analysis to achieve innovation. To assure the case

study quality, validity and reliability of the following set of actions were made: a case study database was created, which included all the primary and secondary data from the case study; a report with the main findings was validated by company's informants; triangulation of information gathered in different sources and with different informants; other sources of evidence such as internal documents and company web sites were used to corroborate findings and increase the case study reliability and validity. For reasons of confidentiality, all customer names and classified information will be omitted. Table 2 contains a summary of the data collection process.

**Table 2.** Data collection summary.

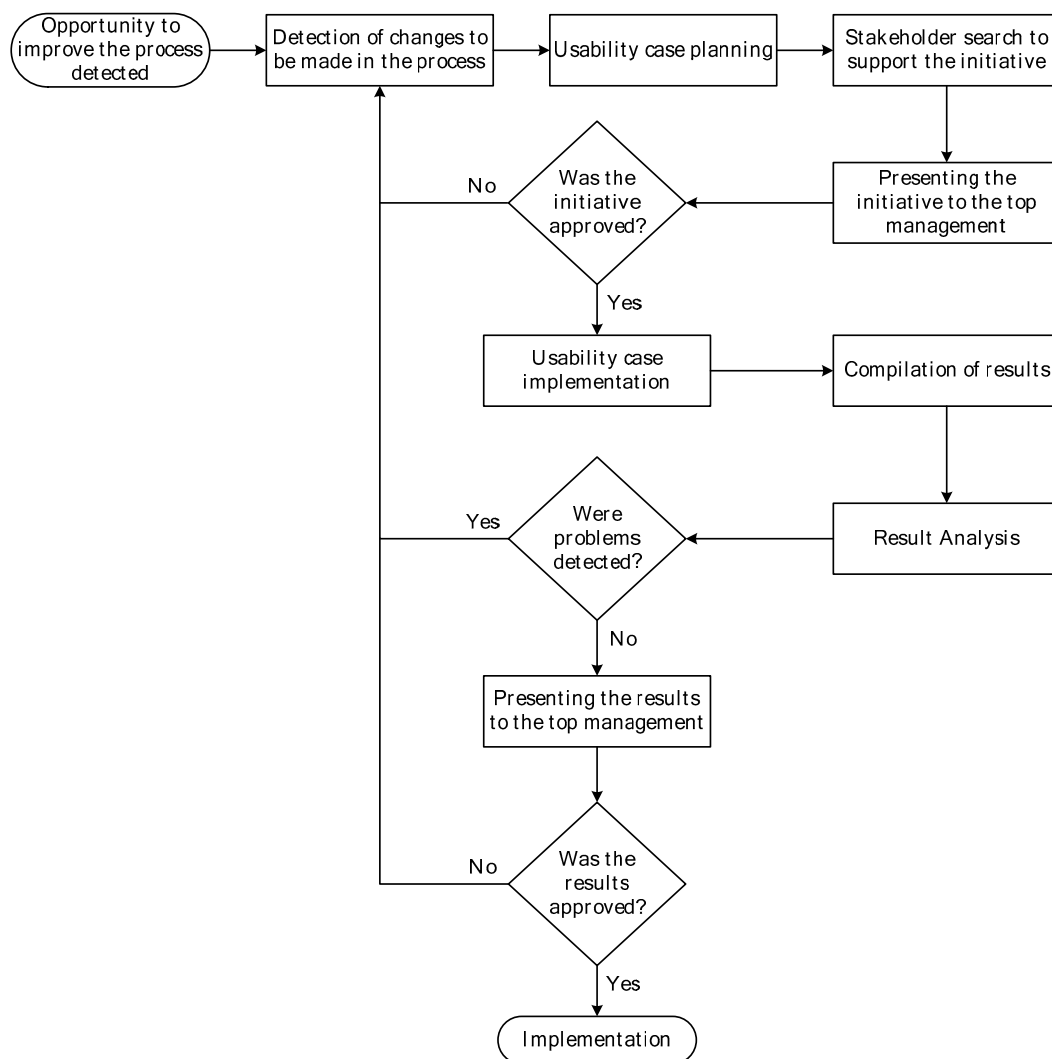
Technique	Data Nature	Source	Objectives
Primary data	Interviews	Description of the current practices and main difficulties faced by the transformation team Existing tools and methodologies used by the transformation team	5 Engineers from the transformation team  Describe the current situation and identifying the main problems
		Barriers and resistance factors to the implementation of transformation projects Mapping process	4 Engineers working on a particular project and Project Managers belonging to the telecommunications infrastructures services department  Describe the current situation and identifying the main problems Nine Windows matrix
	Survey	Project Managers belonging to the telecommunications infrastructures services department	25 questionnaires were answered by project managers
	Workshops	Problems description Top management requirements Requirements for development of the new solution Process operation for existing mapping tools	2 members of the transformation team, the Head of Department, and 4 Project Managers belonging to the telecommunications infrastructures services department  Ideal solution definition Desired requirements for the solution Ideality matrix Contradictions matrix Scenarios comparison using Eco-Compass
	Questionnaires	Data related to the proof of concept of the solution Validation of the proposed solution	3 Engineers working on quality control department  New scenario validation Scenarios comparison using Eco-Compass
Secondary data	Internal documentation such as: Data about company organization and portfolio of services Historical data related to the implementation of transformation initiatives Internal documents related to the existing tools for process mapping		

## 5. Case Study Analysis

### 5.1. Problem Description

The first phase case study was planned to describe the current situation (named by the base scenario). The base scenario under study is related to the procedure that the company uses to collect data and map processes that can be improved and how the case is presented to the top management for approval. It was necessary to identify the life cycle associated with the base scenario, and since it is not a product but a service, it is understood that a sequence of steps should exist until its resolution.

The base scenario, as observed in Figure 4, presents two moments after the implementation of the usability case, in which it may be necessary to redefine the proposed changes and restart the workflow.



**Figure 4.** Base transformation service diagram.

## 5.2. Ideal Solution Definition

To define the concept of the ideal solution of the problem, the TRIZ nine windows creativity technique was applied. Firstly, it was necessary to fill in the system-related window at present, with information on the source of the problem. Subsequently, the supersystem and subsystem were identified within the same timeline, and this process allowed the understanding of the context of the present situation of the system and its surroundings.

After this step, the other cells of the matrix were filled in other timelines, allowing us to understand the progression of the system to the present and what is the preferential trend for its future evolution. In Table 3 the results of the performed exercise can be seen.

However, it is possible to understand that the resistance of management layers to proposed process changes has been increasing over time. This is probably due to the increased competitiveness of the telecommunications market, and the need to maintain customer satisfaction and delays in operations can have major consequences for the company.

**Table 3.** The results of the application of the Nine windows creativity technique.

	Past	Present	Future
<b>Supersystem</b>	Dynamic portfolio, implying a lot of changes in their services over time.	Portfolio restructuring process, leading to the re-design of services and their constituent processes.	Dynamic portfolio, in order to respond to an increasingly competitive market, implying the alteration of its services.
<b>System</b>	Some resistance from the management layer in adopting new tools or working methods to services already in operation.	Too much resistance from the management layer to adopt new tools or work methods in services already in operation.	Little resistance at the management layer to adopt new tools or working methods in services already in operation, as long as they are well-argued and improve their efficiency.
<b>Subsystem</b>	The need to disrupt the operation of work teams in order to test work methodologies or new tools.	The need to disrupt the operation of work teams in order to test work methodologies or new tools.	No need to interrupt the work teams to test new work tools or methods.

It was also identified that to sustain the portfolio dynamism policy and reduce the resistance of the management layers to newly proposed methods, better integration of the improvement processes is necessary. The ideal solution can then be defined as the absence of the need to interrupt the teams' work operation to test the various configurations of services or tools, allowing a greater degree of freedom to perform performance improvement measures. In order to define, then, what are the desired characteristics for the solution to the exposed problem, requirements were defined on what it must fulfill, taking into account the analysis done so far.

It is desired that the method used to create the argument for the adoption of new usability measures or cases be easy to use, allowing its various users to be able to take advantage of the tool without the need for an extended training period. The presented results should be reliable, giving validity to the obtained results, and granting a greater argumentative capacity of the usability cases made. The method should be carried without interrupting the activity of the teams in operation, avoiding a decrease in their performance, and simultaneously reducing the reticence of the management to make new usability cases. This method requires a low level of maintenance, thus reducing the direct costs associated with maintaining the tool in question and encouraging its implementation and use. Additionally, it should be versatile, so that various possible hypotheses can be tested for improvement measures, and assign higher adaptability of the tool so that, in case a usability case planning has been done poorly, or a misstep is detected in the middle of the tool, it is possible to react and respond quickly to it, not wasting the investment made on resources and time.

After identifying the desired requirements for the solution to be obtained, we proceeded to interpret them in the format of the 39 engineering parameters, defined by Altshuller, in order to better fit the TRIZ methodology. The results obtained from this exercise were as follows:

- Usability—Convenience of use (increase):

It is considered important that a user of the new method be able to use it easily in order to increase the usefulness of the tool for it. As such, the association of usability with the convenience of use is considered appropriate, and an increase of this parameter is desired.

- Validity of results obtained—Reliability (increase):

Since the objective of this process is to present arguments for the adoption of a new methodology or tool, it is necessary that they present validity in their results, that is, translate the real system as much as possible, being consistent with it. The validity of the results obtained is then associated with the reliability parameter, preferring an increase in its performance.

- Allocated Time of a Running Team—Harmful Side Effects (Reduction):

It is considered a risk, from a management perspective, that elements of a given project are allocated to a function of which the outputs are uncertain, so this time is referred to as a detrimental side effect. A reduction of this parameter is desired.

- Required tool maintenance level—Automation level (increase):

The level of automation in the context under consideration refers specifically to the need for a human actor to use or keep the tool up to date. It is desired that it is necessary to allocate the minimum human resources for this purpose, allowing their use in operational tasks that generate value for the company. As such, it is desired that this parameter be increased.

- Ability to test different configurations—Adaptability (increase):

Adaptability refers to the ability of the solution to be applied in different contexts. It was then considered to associate this parameter with the testability requirement of different configurations. The more versatile the tool, the better its ability to fit the needs of the business. It is then defined that an increase in this parameter is beneficial to the organization.

Having the engineering parameters defined, it is then possible to apply them in the construction of the system ideality matrix (Table 4), to detect the type of interactions that occur between them. An interaction can be classified as positive (+), negative (−) or non-existent, and these are identified from the question of “if one parameter improves, what happens to the other?” for each possible combination.

**Table 4.** Ideality matrix for the case study.

	33. Convenience of Use (Increase)	27. Reliability (Increase)	31. Harmful Side Effects (Reduction)	38. Automation Level (Increase)	35. Adaptability (Increase)
33. Convenience of use (increase)				+	
27. Reliability (increase)			−	+	−
31. Harmful Side Effects (reduction)		−			−
38. Automation level (increase)	+	+			
35. Adaptability (increase)		−	−		

After identifying negative interactions, it is then possible to approach them through the matrix of contradictions, in order to formulate a solution that does not contain these negative interactions:

- Reliability—Harmful Side Effects:

To increase the reliability of the method employed, it is necessary to better control the usability case variables and/or more repetitions of the method in order to give consistency and statistical validity to the data extracted from them. This implies a longer duration of interruption of the operating teams.

- Reliability—Adaptability:

As mentioned above, in order to increase the reliability of the employed method, greater control of the usability case variables and/or more repetitions of the method is necessary to give consistency and statistical validity to the data extracted from them. However, this rigor in the usability case implementation method reduces the probability of changes to the tested proposal, without reducing the reliability of the results.



- Harmful Side Effects—Adaptability:

In order to infer useful data from the implementation of the usability case in question, if detected the need to change any of the test parameters, it will be necessary to perform more instances of these. However, this implies that more staff time will be allocated for this purpose.

It can be seen in Table 5, adapted from the contradiction matrix for the context of the problem to be analyzed, the invention principles identified as capable of eliminating the identified contradictions. The invention principles were proposed by Altshuller and can be observed in Figure 2.

**Table 5.** Contradictions matrix for this case study.

	33. Convenience of Use (Increase)	27. Reliability (Increase)	31. Harmful Side Effects (Reduction)	38. Automation Level (Increase)	35. Adaptability (Increase)
33. Convenience of use (increase)				1, 34, 12, 3	
27. Reliability (increase)			35, 2, 40, 26	11, 13, 27	13, 35, 8, 24
31. Harmful Side Effects (reduction)		2, 24, 39, 40			
38. Automation level (increase)	1, 12, 34, 3	11, 27, 32			
35. Adaptability (increase)		35, 13, 8, 24			

Note: the correspondence between the numbers in cells and the inventive principles can be found in Figure 2.

For the contradiction identified between the parameters “Reliability” and “Harmful Side Effects”, it is suggested to use the extraction principle (principle 2, as seen in Figure 2) by separating or isolating a part or property of an element.

The principle of copying was also identified and can be implemented by using a simple and inexpensive object instead of an expensive and fragile one, replacing it with a visual copy and/or if it is already used, adopt infrared or ultraviolet properties.

The application of composite materials rather than uniform is recommended, and finally, it is suggested to use the principle of transformation of the physical or chemical state, which can be achieved by changing the physical state of the object, its concentration or consistency, degree of flexibility and/or temperature.

In the case of “Reliability” and “Adaptability”, four principles are suggested, these being the counterweight, which can be realized by combining two elements, or one of these with the environment, to compensate for its weight. Inversion, by reversing the action initially used to solve a given problem, for example, whether it was necessary to heat the system, cool instead, change the dynamism of certain elements between static or mobile or reverse the system completely, colloquially referred to as “turning the object inside out”. Mediation, by using intermediate processes to link subsystems or permit their temporary merging. Finally, the transformation of the object’s physical state by changing its physical properties, concentrations or consistencies, degrees of flexibility or temperature.

As for the contradiction between the “Harmful Side Effects” and “Adaptability” parameters, no inventive principle is associated with its resolution through Altshuller’s matrix of contradictions.

In order to facilitate the consultation process for the elaboration of a specific solution, the identified principles were compiled into a table arrangement, Table 6, as well as their possible applications and how often they were referred to for the various contradictions.

As can be seen, the combination of the principles of “transformation of the physical or chemical state”, “extraction” and “copy” lead to a possible solution that uses simulation models and the combination of “transformation of the physical or chemical state” and “Inversion,” suggests exploring extending tool access beyond just process engineers.

**Table 6.** Frequency of identified inventive principles.

Inventive Principle	Possible Applications	Frequency
Physical or chemical state transformation	Use virtual prototypes, use mathematical simulation models, and/or excite potential product customers by allowing them to make changes to it.	2
Extraction	Outsourcing and/or separating the problem from people.	1
Counterbalance	Raise Stakeholders for a project and/or present management solutions prior to application.	1
Inversion	Allow the system to be used by operational teams rather than just process engineers.	1
Mediation	Hire consultants and/or external quality audits.	1
Copy	Use fast and disposable prototypes, apply process models, use a virtual database instead of paper and/or use simulations.	1
Composite materials	Use hybrid human resources between staff and trainees and/or use various media to provide training to users (video, writing, audio, etc.)	1

The “copy” principle also alludes to the need to think about managing the database responsible for feeding data to a possible simulation model. Applying again the substance-field models, the possible solution configuration is then structured, also allowing one to identify if there is a need to introduce or change any of its elements.

The existing elements in the system remain as the agents that propose the improvement measures, the tasks, or operational processes, having replaced the methodology to be applied by the new solution obtained.

The concluding solution, in order to respond to the identified problem, was using the simulation tools to design new improvement scenarios, giving it simulation capabilities and integrating the process mapping work with the model building work for the simulation. As well as being a solution that uses existing resources in the system, it has also made it possible to build an argument to increase the willingness of project managers to gather information about services so that they can benefit from the planning functions of alternative methods and tools, and at the same time justify a greater allocation of dedicated servers to the tool, improving its performance and user experience.

### 5.3. The Combined TRIZ and Eco-Compass Analysis

The sustainability assessment of the combined solution was then carried out using the Eco-Compass tool. As there is no data available to make a quantitative assessment, a qualitative assessment was used in order to be able to apply the tool.

The new scenario introduces significant changes by replacing the “usability case implementation” and “result compilation” steps with “designed scenario simulation” (as illustrated in Figure 5). This replacement occurs due to the functionality of the simulation software, which allows automatic compilation of the results obtained, requiring only its analysis. The reason that this step is defined in the plural is because it is possible to simulate more than one scenario simultaneously, without the use of relevant additional resources. As a result, the “process change definition” and “usability case planning” steps will also have different dynamics, as there is the ability to analyze more than one transformation proposal at no extra cost. Similarly, if there is a need to restart the flow due to detected problems or not approving the results obtained after its analysis, a smaller amount of resources will have been invested in the construction of usability cases. For this reason, the resistance of the management layers to approve the initiative will diminish.

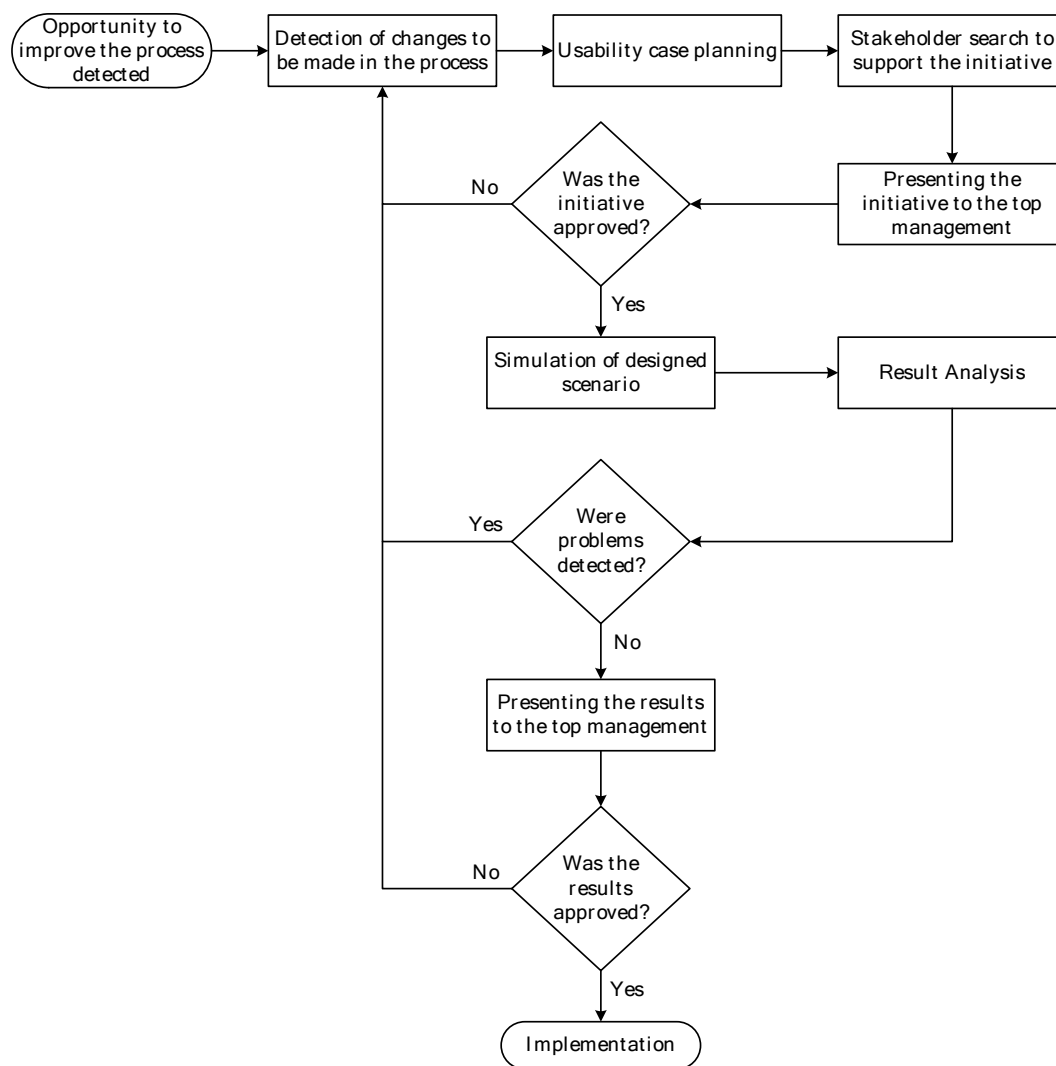


Figure 5. The proposed transformation service diagram.

Having the data related to both scenarios outlined, it is then possible to compare each of the Eco-Compass indices between the two scenarios under analysis. The scale of Eco-Compass represents six dimensions and is evaluated on a 0–5 scale. According to the literature, the reference point is always 2 in each dimension [14,65]. The parameters of the base scenario are set to 2 on a scale of 1–5, and the criteria of the proposed new scenario are determined relative to the base scenario.

Due to the lack of data available to perform quantitative calculations, a qualitative approach was used.

- Mass Intensity:

The difference between the base scenario and the proposed scenario is the introduction of a method of simulation of usability cases, as an alternative to their execution. One of the advantages of using simulation methods over their implementation is that it allows the analysis of various simulation scenarios without actually using their constituent resources.

The scale from 1 to 5, being relative, is usually calculated by the percentage reduction of mass or resource consumption between the two scenarios. As in the new situation, the consumption relative to masses or resources is practically zero; a score of 5 was assumed for this parameter.

- Potential risk to human health and environment:

Following the same logic, for the parameter “Potential risk to human health and environment”, it is understood that by avoiding the need to implement test scenarios to analyze their effects, it is possible to predict and plan control measures in advanced system reactions to new tools or methods. Correct modeling of the system in the simulation software allows analysis of its operation under extreme conditions of use and detection of breakage points, allowing the early creation of preventive measures for the real consequences that may result.

The risk to human and environmental health was, therefore, assumed to be drastically reduced, but the quality of system modeling was crucial to avoid future impacts. For this reason, the score assigned in this field was set to 4.

- Energy intensity:

It is considered that the energy intensity parameter was also reduced by avoiding the implementation process of usability cases, and due to its nature of telecommunications/infrastructures may or may not involve significant energy costs. Another advantage of using simulation is that it is possible, through the processing of several scenarios in parallel, to find the combination of parameters that presents the best energy performance of system components. The score given for this parameter is 5.

- Waste Reuse:

A correctly built simulation model only records waste levels without actually producing them, as opposed to the scenario where the usability case is actually implemented. That is, in the new scenario, waste only exists in digits in software, not constituting real waste. Allowing you to detect when and where they occur before implementing a solution gives you the opportunity to build processes that use the same waste and increase your level of reuse.

It is important to note that a user, modeling a system and testing changes to it, will seek to increase resource efficiency by conserving resources or creating reuse processes, however, their success will depend on their proficiency in detecting them.

Similarly, a model built for the analysis of a particular proposal may be reused to perform a different study, but within the same service scope. For this reason, a score of 4 was assigned in this field.

- Resource Conservation:

In terms of resource conservation, given one of the characteristics of simulation is to allow the analysis of a given usability case without the need for implementation, so naturally, it will not be necessary to allocate them for this purpose. Another feature is that it also allows an adaptation of the process in question to better accommodate the proposed methodology or tool, increasing the efficiency of the resources used, and increasing the performance of this factor. In this field, a score of 5 was assigned.

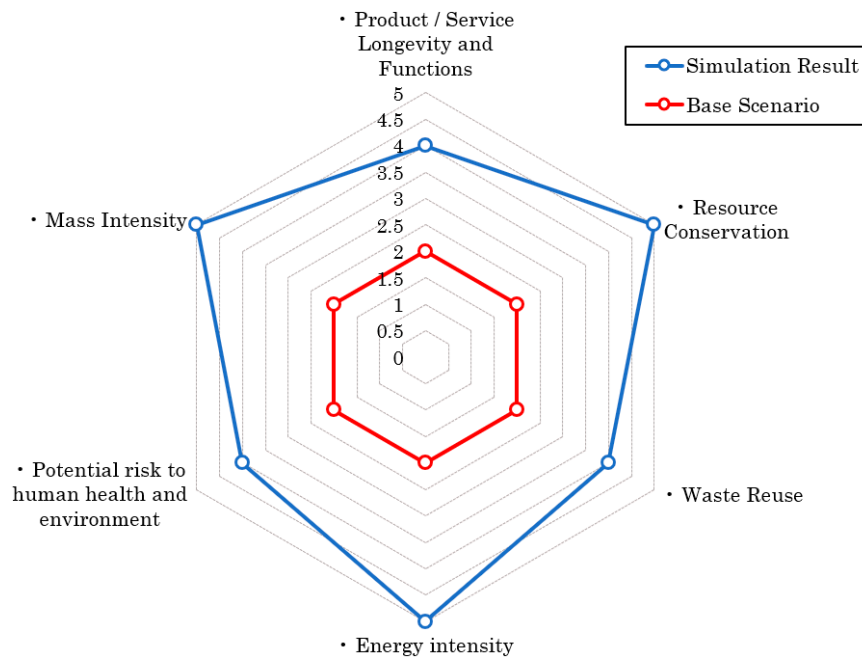
- Product/Service Longevity and Functions:

The models used have to represent the reality of the system to be analyzed, as such, they require constant updating in order to keep current.

However, this information is not intended for a single application for a given service change proposal, but rather to have a database containing existing models, coordinated with the process mapping prepared by the transformation team, so when necessary they might be used. The base scenario is to implement a certain usability case and use its results in order to support the argument elaborated in favor of a service alteration. Once the arguments have been put forward, if the management layers approve, this change can be maintained or changed to integrate more efficiently with other system

processes. However, if the proposal is rejected, the change made to the case of usability is discarded. Using a comparative assessment, the value of 4 is assumed for this parameter.

After the Eco-compass parameters have been evaluated for the proposed scenario, they are inserted in the Eco-compass model, verifying if it meets the sustainability criteria defined as “the improvement of at least two parameters without making the others worse”. The results show that this enterprise meets the sustainability criteria, as can be observed in Figure 6, which shows the results of the evaluation performed under the specific format of the Eco-compass tool.



**Figure 6.** The results of the evaluation performed under the Eco-compass tool.

The final solution, having been approved according to the established criteria, was then proposed to the management layers of the development department, and a usability case was built, based on one of the subprocesses of one of the services available in the portfolio, to demonstrate, in a practical context, the usefulness of the tool.

#### 5.4. Results Discussion and Limitations

One of the strongest aspects of the TRIZ methodology is the concept of ideality added to the Nine windows creativity technique in time. Its use allows an understanding of the system under consideration, its surroundings, the context, and, at the same time, introduces the exercise of designing an ideal scenario for all members of the work team, forcing them to converge their wishes to the future evolution of the system. Due to this, a greater commitment on the part of the collective is reached, facilitating their involvement in later phases of work.

The matrix of contradictions, considered as one of the main elements for the purposes of the proposed methodology, presented some challenges for the team in its application due to the contexts under analysis. Thus, it was necessary to adapt the engineering parameters and inventive principles identified to the context of services, and sometimes this same work presented difficulties, recognizing that experience is a factor that allows improving the performance of this activity.

Since the base scenario was to implement a certain usability case and use its results, a problem surged due to the fact that it is necessary to collect data on the configurations of the processes under analysis, times, costs and other relevant variables. The process of collecting data at the level of processes, or more popularly referred to as data mining due to its volume, is a new complex problem that several companies dedicate a lot of effort to develop and implement. As such, this activity requires

a responsible team for its planning, elaboration and execution. This team has the responsibility to identify each of the processes within the scope of the work and to plan its approach and develop software capable of recording the necessary information such as times, associated costs and other relevant variables for the elaboration of simulation models.

The concluding solution, in order to respond to the identified problem, was to adapt an existing tool, assigning its simulation capabilities and integrating the process mapping work with the model construction work for the simulation. In addition to being a solution that uses resources already existing in the system, it also made it possible to build an argument to increase the degree of project managers' adhesion to the collection of information about services, in order to benefit from the planning functions of alternative methods and tools and at the same time justify a greater allocation of servers dedicated to the tool, improving its performance and user experience.

Finally, the sustainability assessment was carried out using the Eco-Compass tool. As there is no data available to make a quantitative assessment, a qualitative assessment was used in order to be able to apply the tool. After the Eco-compass parameters have been evaluated for the proposed scenario, they were inserted in the Eco-compass model, and it was observed that it meets the sustainability criteria. Thus, through these results, it was possible to attain innovation according to a level of established sustainable environmental parameters, meanwhile solving the inventive problem identified by maintaining the system functions. The final solution was then proposed to the top management.

## 6. Conclusions

The application of TRIZ in distinct sustainability fields of research has been increasingly addressed in the research community, and several studies have addressed and linked in a wide range of areas and applications, from eco-innovation and eco-design to social sustainability and ergonomics.

The purpose of this study was to develop an application model of the inventive resolution theory in conjunction with the Eco-Compass ecological innovation tool, in order to allow solutions to be obtained systematically, and to present a performance increase of certain environmental parameters, promoting thus sustainable innovation. This study addressed a combined use of TRIZ and Eco-compass, especially the compatibility between the Eco-Compass tools and the contradiction matrix. Two new associations were proposed by the authors between Eco-Compass tools and the contradiction matrix. The purpose was to evaluate and validate a process that is part of the department of transformation and continuous improvement of a telecommunications enterprise offering a set of services to be applied to telecommunications infrastructures. Therefore, the validation of the model was made through the accomplishment of a case study at Nokia enterprise in organizational contexts and different technological sectors. A problem surged since it was necessary to collect data on the configurations of the processes under analysis, costs, times and other relevant variables, and it was not made properly until then. In order to respond to the identified problem, the solution was to adapt an existing tool, assigning its simulation capabilities and integrating the process mapping work with the model construction work for the simulation. The Eco-compass results showed that this enterprise met the sustainability criteria. Thus, through these results, it was possible to achieve innovation according to a certain level of established sustainable environmental parameters, while at the same time solving the inventive problem identified by maintaining the system functions. This solution of this model was proposed to the management of the development department and was approved, and a usability case was built.

Based on the conclusions inferred from this study, and in order to ensure continuity, it is recommended for future studies to perform further case studies. More case studies need to be made, bearing in mind the need for reinforcement from organizations in insisting on more demanding sustainability criteria for the obtained solutions, in order to study the impact of engineering parameters derived from the application of Eco-Compass. As such, it is suggested to focus future work on companies or organizations that present profiles with a higher focus on sustainability.



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